AN INSPECTION ORGANISATION—DETAILS OF SOME METHODS AND EQUIPMENT.

Paper presented to the Institution, Luton, Bedford, and District Section, and Western Section by M. C. Park, M.I.A.E.

Organisation.

THE prime function of an inspection department is to safeguard the quality of the products, to prevent defective materials or incorrectly made parts from being used, and in the interests of economy it is essential that any defective material or work is found and rejected as early as possible in the manufacturing processes. In this paper we are dealing with an inspection department of a concern manufacturing motor cars and commercial vehicles. In order to understand how an inspection department operates in conjunction with other departments, it will be helpful to briefly survey the general organisation of a modern manufacturing undertaking.

Briefly, the functions are as follows : *Directorate and Administration*—Controls and covers all departments. *Financial*—Looks after all cash, accounts, and costing. *Engineering Department*—Responsible for all product designs and specifications. *Metallurgical and Laboratory*—Responsible for the specifications of all materials used in the products and manufacturing processes. *Supply and Purchasing*—Responsible for the purchase of all materials, both productive and non-productive, and manufacturing schedules. *Production Engineering*—Responsible for the design, specification, and manufacture of all machinery and equipment. *Standards Department*—Responsible for methods of payment, production operation times and maintenance and issue of routing or operation sheets. *Inspection Department*—Responsible for the quality, accuracy, and finish of all products passed to the sales department. *Sales Department*—Sells all products. *Service Department*—Looks after them when they are sold.

The objectives of such an organisation are the delegation of definite responsibilities and control of expenditure, and each department is allotted a proportion of the income from sales to carry out its functions. The basis of all effective production is complete and accurate specifications. In the type of concern with which we are

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dealing, the specifications are issued from the engineering department in the form of blueprints for components and assemblies, standard parts lists for such parts as bolts and nuts, screws, rivets, washers and cotters, etc., and specification sheets and lists of all materials.

The inspection department is organised under two main headings : (1) Receiving inspection, which includes inspection in the works of suppliers ; (2) Inspection in the production divisions.

Receiving inspection is responsible for inspecting all incoming materials for quality and dimensional accuracy before they are passed to the stores or the production departments. Inspection operation sheets are issued which set out the inspection operations necessary and they also show the percentages to be inspected. In many cases percentage checks are made, and where these are specified, it is understood that if any of the percentages inspected are found faulty, the whole of the batch is inspected. Inspection in the production divisions or shops is carried out by floor or patrol inspectors, bench inspectors, and assembly inspectors.

Floor Inspectors are responsible for the inspection of components during the processes of machining, pressing and assembling of parts, and the size of the area they patrol depends on the class of work which is being done and the productivity of the machines, and varies from 10 to 100 machines. By frequent checks of the parts off the machines, floor inspectors are expected to detect inaccuracies before a serious quantity of defective parts have been produced. Floor inspectors are also responsible for passing samples after a machine has been re-set-up and before a production run or batch is commenced.

Bench Inspectors inspect batches of finished or semi-finished parts in a routine manner with whatever equipment is necessary and in accordance with inspection operation sheets.

Assembly Inspectors are installed on assembly lines and inspect the assembly of engines, gear boxes, rear and front axles, and body building, painting and trimming, and complete car and truck assembly.

Inspectors also work as testers and carry out inspection operations on units such as engines and gear boxes, which are given running tests as units before they are assembled into cars, and they also test cars and trucks on roller and road test before they are passed over to sales.

In addition to the foregoing inspectors who are located in producing divisions, a headquarters inspection staff is maintained, where samples of all new parts are passed before approval is given to go ahead with the production of an entirely new part. These inspectors are also responsible for carrying out systematic inspection of units and important components in a more thorough and detailed manner than is possible in the shops. Complete units, such as engines, gear

boxes, axles, etc., are taken daily from the departments producing them and dismantled and meticulously checked throughout against the specifications. The facilities of the headquarters inspection are available to floor inspectors, trouble investigators, inspection executives or to any other department or outside supplier in times of difficulty. Inspection headquarters' staff also follow up and log the introduction of changes in design, and advise the service and other departments when changes are effective and the number of the first chassis incorporating the new parts. Inspection headquarters' staff also co-operate with the production engineering department in the maintenance and provision of inspection equipment, and issue and keep inspection operation sheets up to date. All suggested changes in limits from the shops are passed to the chief inspector for his comments before being passed to the engineering department, and any necessary investigations arising from change requests are investigated by the headquarters' staff.

Methods of Inspection.

The number of different components which go to make up a complete motor car runs into several thousands, and in order to deal with the methods employed within the limits of a paper like this, I have taken two different components only, and have set out precisely how they are inspected and the many indirect inspection activities which arise during the production of them. I hope that by taking you over the inspection of these items in this way, you may obtain as complete a picture of the inspection organisation and methods as is possible in the time at my disposal.

Taking an engine connecting rod, a quotation for a quantity of these stampings having been obtained from an approved source of supply by the supply and purchasing department, the work of the inspection department commences on this part. Contact is made with the representative of the works' department making the stampings, and the planned methods of machining and inspecting the stampings, the location points for machining and the machining allowances are made clear by the production engineering and inspection departments. It is also a good plan to have all stamping dies numbered, because a number of dies are often in operation at the same time. This permits stampings which are giving trouble during machining being traced back to a particular die with obvious advantages.

Making requirements clear to suppliers before they begin to make their own equipment is essential and saves a lot of trouble afterwards. Suppliers of steel stampings are also advised that they are expected to make their own internal arrangements whereby a particular batch of stampings can be traced back to a particular cast or mill lot of steel, so that in the event of trouble with the material,

the remainder of the faulty cast of steel can be isolated in their works or stores and dealt with according to the circumstances. A copy of the material specification sheet having been sent with a blueprint of the connecting rod and the requirements of the production engineering department having been made clear, the suppliers are asked to go ahead and send in a sample. It is understood that a production batch is not put in hand until a sample or sample batch has been approved by the inspection department, which implies that other departments, such as production engineering, design, and metallurgical departments are satisfied.

A sample connecting rod stamping having been received, it is lined out by the sample inspector, who reports on all aspects of it, and the lined out sample and a copy of this report is passed to the production engineer for his comments. When the sample is satisfactory or sufficiently so to justify the belief that any minor faults can be put right by the supplier without the necessity for a further sample, the supplier goes ahead with his stamping work on the bulk supplies.

Every effort must be made to obtain satisfactory samples. This may entail an outside inspector, who is familiar with all aspects of the operations, being located in suppliers' works for an unlimited time, but the correct results justify every possible effort being made when production volume is considerable. When the first production batch is received, the stampings are checked for quantity by the receiving stores, and a stores checking form, together with the batch of stampings, is passed to the receiving inspection.

The first two inspection operations are to Brinell the whole batch of stampings and take drillings from one stamping, and pass same and the Brinell readings to the laboratory for a report on the material. This is done on laboratory form for analysis and Brinell report form, and a small linen envelope is attached to the former, which takes the drillings.

While the laboratory is checking the material, the batch is inspected as follows: 100 per cent. check in fixture, in which the stampings are located on the $1\frac{1}{8}$-inch radius on the back of the big end and one side of the small end boss, which are the locations for machining. In this fixture the checks are: (1) Length with a sighting gauge for the small end boss; (2) Machining allowances on the joint face and bore and width over bolt bosses and side identification web.

Checks out of the fixture are: (1) Thickness of small end boss, adjustable gap gauge, limits .791/.771; (2) Thickness of one section, A.G.G. .525/.505; (3) Width of big end, A.G.G. 1.324/1.304; (4) Visual check for excessive flash, rough clipping, flaws, and offset.

If the laboratory report is satisfactory, the checking form is completed showing quantity passed and quantity rejected. The good ones are then passed to the stores and the rejected ones are

covered by a defective material ticket in triplicate, showing part number, name, quantity rejected, fault, and the name of the supplier. The defective material is then considered by the chief inspector or his nominee, who decides what shall be done with it. His decision falls in this case into one of three categories, either " use," " rework," or " return to supplier." He punches the D.M. ticket accordingly, and the material is dealt with.

The first production operations are: Rotary shot blast; coin big and small ends and centre and straighten. The bench inspection operations following are: (1) Check width of big end, A.G.G. 1.285/1.281; (2) Check thickness of small end, A.G.G. .763/.759; (3) Check thickness of one section, A.G.G. .510/.490. Floor inspection looks after straightening.

Additional function of the inspector is to count for payment when payment is based on quantity produced, and the count is also necessary to maintain accurate production schedules. The good rods are passed to the next operation covered by a material movement ticket showing quantity passed for scheduling purposes and the department to which the material is to be passed for the next operation. The quantity of good rods is also logged on an inspection receipt report for bonus payment purposes. No material is moved unless the movement ticket is completed. The defective rods are rejected and covered by a D.M. ticket, and passed to a reject bench or area to await disposition, which in such a case falls into one of four categories, either " use," " rework," " return to supplier " or " scrap."

In giving dispositions in such cases as this, where productive labour has been expended on the parts, the member of the inspection staff responsible also shows on the D.M. ticket further information. When reworking or salvaging is decided on—method of reworking and department doing the reworking, and the department and account to which the reworking labour and material are to be charged. When scrapping material—operation number at which the material is scrapped, and the group and division responsible for the scrap.

The managers of production divisions, and managers of other departments affected, are posted on the following day with a summary of the cost of all material scrapped or reworked against them during the day. This may seem a complicated and expensive system to maintain, but it is definitely worth while in that it provides all the information and data necessary to keep a close control on the expense of defective work and materials. In addition, production managers and foremen keep a close watch on the D.M. tickets made out in their areas, and have every opportunity of studying same and collaborating in the dispositions. The inspection

department's decision is, however, final in all cases where agreement cannot be reached, which is not often.

The next production operations on these rods are carried out on a line of machines specially set up for the purpose.

During the machining operations on the line, inspection is done entirely by the floor inspector making his frequent periodic checks of all operations, and it is not until the machining of the rod and its cap, which has been similarly handled, has been completed that the rods are all inspected by a bench inspector located at the end of the line.

The bench inspection operations cover the whole batch and are: (1) Big end bore for size and finish, go-and-not-go plug gauge 1.750/1.7495; (2) Width of big end, A.G.G. 1.2445/1.2405; (3) Small end bore for size, blowholes, and finish, go-and-not-go gauge .7506/.7501; (4) Check weight and grade for same; (5) Visual check for bonding of babbit metal and oil holes.

Connecting rods are graded for weight and are kept within one quarter oz. in any one engine, and are painted with colours for identification. Five per cent. of rods are also checked for bonding of the metal by immersion in paraffin and afterwards pressing the edges. The bonding is further checked by damaging the babbit metal in rods which are rejected for blowholes or faulty finish. Good rods are counted for bonus and for scheduling, and passed on to engine assembly.

Example of Gear Inspection.

The gear in question is a 40 tooth, 7-D.P., 20° P.A. spur gear. Owing to the nature of the duty of the part, the reaction of the material during heat treatment and its "machinability" the specification must be strictly adhered to, and is as follows:

Carbon	.010 — 0.14	per cent.
Silicon	maximum 0.30	,,
Sulphur	,, 0.04	,,
Phosphorus	,, 0.04	,,
Chromium	,, 0.10	,,
Manganese	0.25 — 0.50	,,
Nickel	4.5 — 5.2	,,

Samples are approved exactly as in the case of the connecting rod stamping, and the receiving inspection fall to work on the first batch. The whole batch is Brinelled, and the Brinell readings and drillings from one stamping are passed to the laboratory. Drillings are taken from more stampings in cases of doubt. In the case of gear blanks, it is very important that the normalising operation has been properly carried out on account of its effect on cutter wear and cost of cutters, and the effect of rapid cutter wear on the accuracy of the gears being produced. The receiving inspection

checks for dimensional accuracy are carried out in parallel with the investigation of the material, and are made with a rule and ordinary callipers. Good blanks are passed to the gear shop and unsatisfactory ones rejected.

The first production operation is, face one side, drill, and ream bore. This operation is inspected by the floor inspector, who makes checks approximately every half hour as follows: Bore for size, go-and-not-go plug gauge 1.863/1.861; width of blank, A.G.G. .655/.645.

The inspector stamps each blank he checks and finds correct, and leaves it with the operator as a sample. If the operation is not correct, it is stopped until another sample has been passed by the floor inspector.

The next production operation is, surface grind both faces. Inspection by the floor inspector consists of check for width A.G.G. .627/.623; check for flatness by marking on a surface plate. Correct samples are again stamped by the floor inspector, who has an individual stamp, and are left with the operator.

The next production operation is: Round broach bore, and this is again checked by floor inspection (1) with a go-and-not-go plug gauge 1.867/1.866; (2) for squareness of the bore with the ground face by mounting the blank on an arbor—which is a push fit in the bore—between centres. The blank is revolved by hand while a dial indicator is applied to the face—maximum runout allowed at 3-inch radius is .0015-inch = .0005 per inch.

The blank is again stamped and left with the operator. An important point to remember on these percentage checks is that in the event of the floor inspector finding the blank outside the tolerance, all the blanks which have been through this operation since his last check are segregated and checked in this way.

The blank is then turned on the outside diameter, and a floor inspector again makes periodic checks: (1) On outside diameter A.G.G. 5.939/5.933; (2) Runout on outside diameter by mounting the blank on an arbor between centres and taking the reading on an indicator—maximum runout tolerance is .003-inch.

At this stage of production the whole batch is inspected by a bench inspector, who makes all the foregoing checks on all the blanks with the same type of equipment, the only exception being the check for flatness, which is a 20 per cent. test with a straight edge. The bench inspector also visually inspects all the blanks for flaws, some of which are only exposed after machining. All good blanks are stamped with a number peculiar to the bench inspector, covered by a movement order, logged for bonus purposes and routed to the next operation. Defective blanks are covered by D.M. tickets and put on the reject bench for disposition by a member of the inspection staff. The gear blanks are then mounted on an arbor just easy

enough to let the surface ground faces take control, and the teeth are rough hobbed.

One floor inspector is allotted to gear cutting machines, and during rough gear cutting makes as many checks as possible on a " Parkson" tester for : (1) Amount of stock left for final hobbing and pitch line eccentricity and number of teeth. An allowance of .018/.012 on each side of flank is made for the finishing cut. Maximum eccentricity allowed on rough hobbing is .004-inch. (2) Root depth. It is important that the gear is rough hobbed to the finished root depth in order to prevent the finishing hob from overloading at the tip and thus introducing inaccuracies into the tooth curve below the pitch line, due to the breakdown of the cutter edge at this point. The floor inspector again stamps each gear he finds O.K. at this operation and leaves the gear with the operator, and stops the job if anything is wrong.

After rough hobbing comes finish hobbing. The operations are again inspected by a floor inspector, and the limits are : (1) Involute curve .0004-inch/.0000-inch ; (2) Spacing (adjacent teeth) .0002-inch ; (3) Concentricity at pitch line .003-inch ; (4) Tooth size and backlash with mating gear .008-inch/.005-inch ; (5) Alignment of teeth with axis .0002 per inch.

The involute is checked on a Lees-Bradner tester, which consists of a central arbor on which is mounted a base circle of suitable diameter. The gear to be tested is mounted on the same arbor and locked in position. A bar which is ground and lapped is then adjusted laterally so that it forms a tangent with the base circle. Mounted on the " tangent bar " is a dial indicator graduated in ten-thousandths of an inch, and driving this is a tracing arm which is adjusted to the gear tooth at the root or immediately above the fillet at the root. The indicator is set to zero with slight tension on the spring, and the tangent bar is rolled round the base circle describing a true involute, thus any deviation from the involute is transmitted to the indicator.

The gear is inspected for spacing errors on a modification of the same piece of equipment, and consists of a bracket on which is mounted a stop to be used as a datum line which contacts with and fixes the position of a tooth at any point on the tooth, and a lever which contacts at a point on an adjacent tooth. This lever drives a " ten-thousandth " dial indicator. The gear is indexed by hand, and a different tooth brought up to the stop each time. The position of the flank of the adjacent tooth relative to the stop which is constant is then determined by the lever, which is positioned by this tooth, the difference from tooth to tooth being shown on the indicator.

The check for the size of the gear teeth and the concentricity of the teeth is carried out on a standard Parkson tester. The test centres are set with setting discs of suitable diameter, and on the

fixed side of the tester is mounted a master gear of known size. The gear to be tested is mounted in mesh on the moving sides to allow the gear to be rolled deep in mesh. The amounts of backlash and eccentricity are indicated on a dial indicator.

The check for alignment of the teeth with the axis of the gear is done by mounting a gear on centres. A ground test bar of suitable size according to the diametrical pitch and long enough to magnify the error approximately five times, is inserted between two teeth of the gear at a point convenient for passing a dial indicator over the ends of the bar. In this way the amount of deviation of the gear teeth from a plane parallel with the checking centres is obtained. The maximum tolerance is .002 per inch. The floor inspector also keeps a close watch on finish, and if the particular gear he is inspecting is not within all the limits laid down, it is rejected, and the same process of inspecting is carried on until a correct gear is obtained.

These checks are also made and a gear approved by the floor inspector before work on a batch is begun after a hob is reground, moved to a new cutting position or when a new hob is being used. The degree of accuracy and the finish of the gears coming off the machine being the guide for cutter adjustments and changes.

When the finished cutting operation on a batch of gears is completed, the batch is passed to a bench inspector, who inspects the whole batch for size, concentricity, and finish on the same kind of equipment as the floor inspector uses. Correct gears are all stamped with the inspector's number and passed to the heat treatment department. Movement tickets being the method of controlling and advising the truckers on the necessity for moving and the destination of the parts, and D.M. tickets controlling the rejects.

The inspection of the carburising operation is based on test pieces of the same material, which are placed with the gears in the carburising boxes. After 5½ to six hours soaking at a maintained temperature of 980 degrees Cent., the test pieces are removed, reheated, and quenched in water, and broken to enable the inspector to take a reading on the carbon penetration.

The limits are .7 to .9 m/m., and the depth is read by a glass giving several magnifications with a scale attached to the front of the lens. If test pieces are passed, the batches are passed on for reheating, quenching, and tempering. If the case of the test pieces is not deep enough, the batch is rejected and reworked. Percentage checks are then made: (1) To ensure that the requisite hardness of the case has been obtained; and (2) To ensure that the quenching and tempering operations have been carried out correctly.

The hardness is checked on a Rockwell or Avery hardness tester, and the minimum hardness value is 55C. The check on the quenching

and tempering to check for the silky notched fracture called for on the specification is obtained by breaking one gear out of every batch. Good gears are then routed to the next operations of wire brushing to remove dirt and scale, and grinding the bore. After grinding, the bores are checked with a plug gauge, the limits being 1.8755/1.8750. After this the gear teeth are burnished which irons out slight abrasions which the teeth may have suffered during heat treatment, and the burnishing operation also gives the teeth a polished surface.

The gears are again 100 per cent. inspected by a bench inspector for: (1) Size of bore; (2) Finish of teeth; (3) Cleanliness; (4) Noise test.

For the latter the gears are mounted on standard centres and driven at varying speeds from 400 to 1,000 r.p.m. The gears are tested both loaded and unloaded, and for the guidance of the inspector on this test he is supplied with known quiet gears, which are removed from gearboxes which have proved quiet on road test. The chief value of this inspection is that it quickly shows up gears which are noisy due to small abrasions, due to handling in the heat treatment and other operations.

The writer believes that the fundamental quietness of gears rests on the ability to work to extremely close limits, and he also believes that in some cases it is not the theoretically perfect form which gives the best results, but slight modifications from it which counteract spring in the structure of gear arrangements, and the only way to discover such modifications, when they are necessary, is by trial and error under actual working conditions. After this inspection, the gears are passed to assembly, and are finally noise tested as a unit, the good ones passing to car assembly and the noisy ones back for reworking.

Disposition of Materials.

Of the form used in the inspection department the one of outstanding importance is the defective material ticket. The defective material ticket is the only means by which decisions or dispositions on any material can be given throughout the works.

There are four major ways in which this ticket is used: (1) When defective material is received and rejected in the receiving inspection; (2) When defective material is scrapped due to our own operations, i.e., through faulty work, tools, damage, etc.; (3) When defects in the material are thrown up during processing operations in the works; (4) Disposal of obsolete parts.

(1) Rejecting of Defective Material by Receiving Inspection.

All material received is inspected by the receiving inspectors, located at various points where material is received, and when material is rejected on the supplier, the date, part number, name

of the part and quantity of material rejected (also the name of the supplier where possible) are shown on the defective material ticket. Dispositions given are either " use," " return," or " repair," and the defective material ticket is punched accordingly.

In some cases defects are found in material, but owing to production requirements and the nature of the defects, it is not advisable to reject it to the supplier but to repair it at the supplier's expense. In these cases the defective material ticket is punched " R card " and the tag is also punched " repair " and shows the nature of the repairs and the department in which the reworking takes place. If the repairs are of a very minor character and for some reason it is not considered advisable that the supplier should bear the cost, then the defective material ticket is punched in the " 722 " column and charged to Division 61—purchasing—which indicates that we are rectifying defective material at our expense. These cases should not be numerous, and as far as possible should be agreed by the purchasing division and passed by the chief inspector.

(2) Defects arising from our own Operations.

Here again the defective material ticket is partially completed by the inspector who discovers the fault, and he fills in the date, part number, part name, quantity, operation number, group, and the nature of the defect. Dispositions on such material are given in all cases by the chief inspector or his nominee. These dispositions show whether the material is to be used, returned, repaired, or scrapped. If the material is to be repaired and the responsibility for the repairs is ours, the defective material ticket is punched " repair " and account " 721 " and the nature of the repair, the department reworking and the division chargeable with the cost of the work are also shown.

(3) Defects Brought to Light during Processing Operations.

In such cases the defective material ticket is partially completed by the inspector responsible for inspecting the component, and shows the date, part number, part name, quantity, operation number, group number, and the nature of the defect. Dispositions are given as under heading (2), and in such cases a decision has to be taken regarding whether the work should be charged to the supplier or borne by us. If the former the defective material ticket is punched in the " R card " column, and if the latter the " 722 " column. Here again there must be a very good reason for our undertaking to bear the cost of making good defects on faulty material. In all such cases the rectification work should be of a minor character, and whenever possible, agreed by the purchasing division and passed by the chief inspector.

(4) Disposal of Obsolete Parts.

When obsolete parts are thrown up due to either engineering changes or model changes, lists of such parts are compiled by the inspection department and passed to the supply department, who are responsible for finding out if such parts can be absorbed by spares department. When the supply department have satisfied themselves regarding disposal of such parts, they advise the inspection department, who route quantities which can be used and give dispositions on the balance. Before scrapping such parts or rejecting them to the disposal department, the inspection department check through each of the items again, with a view to confirming that it is not possible or economical to use or alter such parts for production or for parts department.

Distribution of Copies.

The stiff copy of the defective material ticket in all cases goes with the material either to the department in which it is to be repaired, to the stores when material is being returned to the supplier, or to the by-products division if the material is scrapped. The two flimsies are in all cases passed to inspection headquarters, where after examination the top copy is passed to the cost office and the other flimsy to the material division. In the event of material or parts of an assembly which have been sent for repair having to be subsequently scrapped by the department doing the repairs, a further defective material ticket is necessary showing the parts which are scrap.

Notes.

(1) When material is faulty, defective material tickets are in all cases punched " return." No defective material should be scrapped. The only exception to this is the case of sheet steel in the press shop where tolerances are fixed to cover wasters from pressing operations; in such cases there are tolerance percentages agreed for the range of pressings, and such percentages of faulty pressings made during a run are accepted as our responsibility. In these cases separate defective material tickets are made out showing quantities for which V.M. are accepting responsibility, and the remainder shown on defective material tickets punched " return."

(2) Small pieces of bar or odd pieces of material which are too small to be worth while returning to suppliers, are punched " scrap " and also " 722 " and charged to Division 61 (purchasing).

(3) When dispositions are given regarding material and defective material tickets are punched, the two top copies are at once torn off and passed to inspection headquarters.

(4) I.W.O. numbers are issued and referenced to engineering changes as they are issued. Therefore, when any reworking becomes

necessary owing to an engineering change, the I.W.O. number must be shown on the defective material ticket, so that the department reworking can use it to cover the reworking.

(5) When a defective material ticket is punched in the " R card " column, one copy of the ticket showing the estimated cost of carrying out the work is routed direct to the purchasing division.

As far as possible " R card " numbers should be available before dispositions are given, but in order to avoid production hold-ups it is necessary to send copies of the defective material tickets to the supply department and the cost office without the " R card " number, but the " R card " number must in all cases be shown on the stiff copy which accompanies the parts to the divisions where they are being reworked in order that it may be shown on the group allowance card.

(6) If it is necessary to alter defective material tickets for any reason, all the three copies must be altered.

Discussion, Luton, Bedford and District Section.

Mr. J. Ronald (Section President, who presided) thanked Mr. Park for a very interesting lecture.

Mr. Bamford stated that during the exhibition of the lantern slides, several of the gauging devices had appeared to be mounted on somewhat flimsy types of tables, and he wondered whether the vibration in the machine shops was likely to upset the reading of the dial indicator, and if so, what steps were taken to safeguard this problem?

Mr. Park replied that although in one or two instances the gauging equipment may " appear " to be mounted in an indifferent manner, the equipment itself is more than rigid enough to withstand any vibration emanating from the machine shops, and he had experienced no difficulty in this direction.

Mr. Gilbert stated that there was one very important point that Mr. Park had not stressed, which probably gives both inspectors and producers more trouble than anything, i.e., where an inspector is responsible to a very large extent for the " degree of finish." For instance, in a motor car factory, an inspector has to " pass " such work as body painting and trimming. You cannot apply gauges for this type of work, and that is where a great deal of responsibility rests upon the inspection department, and is a problem which can only be adequately met by tact and firmness on the part of the inspector. Another point stressed in the lecture, which he—as a production engineer—was in agreement with 100 per cent., was that it is well worth while going to the trouble and " apparent " expense in detecting errors in castings, stampings, etc., at as early a stage as possible. This has a big advantage in a shop where men are being " paid by results." As an instance, take a cylinder block line. Blowholes, which by taking more care, could have been detected at one of the initial stages, are not discovered until the components have passed a considerable distance along the machine line. This means that the operators are paid for all the operations up to that stage on components which are nothing more than scrap, thus causing considerable waste of money. The production man had no better friend than what is known in the shops as a " red-hot inspector," and he fully agreed with Mr. Park in that the more time—and probably money—spent in detecting errors at the correct stage, the greater the overall saving.

Mr. Mills, regarding the " burnishing " of gear teeth, asked exactly what was done, and the effect on the finished gear. He confirmed Mr. Park's views regarding the importance of numbering forgings received from the stampers, and in a like manner the

numbering of castings—particularly malleable castings—received from the suppliers. One of the biggest helps a shop could get came from the man who was able to detect a faulty casting or stamping in its initial stages. He also referred to the " tight " limits on the end of connecting rod stampings, and stated that he imagined such results would be rather costly from the point of view of maintaining the " dies." As to the checking of differential gears when mounted on bearings, his method would be to check the bearings independently, and he suggested that this might be a better method, although a more lengthy process.

Mr. Park explained that burnishing is done merely to " iron out" the cutter marks on the teeth ; it is not overdone so as to upset the form of the teeth, but simply to " surface." In some quarters burnishing is considered unnecessary, but his experience convinced him of its advantages, and as it had been the means of obtaining very good results on gears, he saw no reason to discontinue it. On the question of piston castings which cause certain trouble for no apparent reason, these were probably in a ratio of two or perhaps three troublesome castings in twenty. Very often the cause of the trouble cannot be located until machining is well on the way. Arrangements are made with the suppliers of piston castings so that in the event of running into trouble they are told not to send in any more castings made during that week. They are told that we are willing to machine them providing that they (the suppliers) will agree to stand their share of the cost in the event of scrap. This has the desired effect of making casting suppliers very careful.

Regarding connecting rods, he agreed that the question of dies was an important one, and he stated that 1/2 doz. sets of dies were working. As a result of the close tolerances on the ends of connecting rod stampings, the faces were coined instead of being milled. In coining connecting rods, the amount to which you size them depends upon the width. Obviously therefore, it is desirable to keep the coining allowance down to the absolute minimum. This plays an important part in maintaining coined parts within the necessary limits.

In connection with the method of inspecting differentials, due to " life being so short " the whole thing is checked at one setting. It was considered unnecessary to check the bearings separately as ball bearing manufacturers check their own products, and it is very seldom an inaccurate bearing " passes."

Mr. Rigby referred to a paragraph in Mr. Park's paper dealing with the manner in which certain items of expense were charged to the various departments concerned. Did the inspection department ever find it necessary to allocate any of these expenses to themselves, or were they always able to inflict such expenses on

some other department other than their own?

Mr. PARK replied that it certainly had been known for the inspection department to allocate some of these expenses to their own department—*but not very often.*

Mr. BAMFORD asked if there were any means of testing connecting rods for balance during machining operations. If merely coined, might not a bigger volume of metal in the large end upset the functioning of the engine?

Mr. PARK said that at one time both small and large ends were weighed and balanced. This is no longer necessary, and the present-day method is to weigh the complete connecting rod.

Mr. RONALD added that it was still necessary to check both ends of the connecting rod when required for aeroplane engines, as in this type of product every care must be taken, and the connecting rod is machined all over, and carefully balanced. It is absolutely unnecessary, however, in the case of connecting rods used for motor car engines. He would like to ask Mr. Park the method employed in testing the babbitting of connecting rods, i.e. as regards the adhesion of the babbit-metal to the steel.

Mr. PARK replied that connecting rods were merely immersed in a paraffin container. They are then placed on small trays for an inspector to try to squeeze paraffin out. If the babbit-metal has adhered satisfactorily no paraffin can be squeezed from the "joint." This test is applied to five per cent. of the connecting rods produced, and very little trouble is experienced in this direction. In addition, there are inspectors looking after the connecting rod line, carrying out such functions as checking the temperature of the babbit-metal, and having every consignment of babbit-metal checked by the laboratory to see that it conforms to specification.

MR. RONALD asked Mr. Park if he would explain the principle of heating in order to obtain satisfactory adhesion of the babbit metal to the connecting rod.

MR. PARK explained that the connecting rods were first of all wire brushed with flux, the big end immersed in the tinning bath for approximately one and a half minutes and heated to a temperature of 300 degrees C. When the rods are removed from the tinning bath they are then placed in the die at a temperature of 370 degrees C. It is very important to maintain the die at the correct temperature. Although some trouble was experienced at first in getting this babbitting plant running, it was now functioning satisfactorily, and a good "bond" is being obtained.

MR. ARTHUR asked whether the gear teeth received any treatment such as "lapping" after grinding, hardening, etc.

MR. PARK replied that as regards gearboxes for commercial vehicles, the gear teeth are not lapped. In the case of gears for passenger cars, the teeth are given a lapping process, sometimes

"together," sometimes singly. There is no hard and fast method; it depends on the ultimate requirements of the finished job, but every care is taken to see that the desired results are obtained.

Mr. Ronald referred to the method of checking camshafts. He wondered if camshafts could be more quickly examined by using an indicator chart, taking the cam along the line. He remembered a fixture being designed for this purpose some years ago, which had apparently been satisfactory.

Mr. Park replied that he had not considered making a fixture of this description. The method employed, i.e., the check on the point of maximum lift, is very quickly obtained. The first camshaft checking fixture was designed ten years ago, and a second similar fixture had since been made. The tolerances worked to on camshafts and gudgeon pins were extremely "tight" and he had never seen parts made in smaller quantities—though at a much higher cost—result in anything like such a good "fit." He well remembered when arrangements were first made to produce "Chevrolets" in Luton. Component drawings were obtained, and in the case of the gudgeon pin, it was noticed that the drawings indicated a tolerance of .0001 inch. This was at first thought to be a mistake—that the decimal point had been put in the wrong place. However, samples were obtained, which were within the .0001 inch tolerance, and although we were at first inclined to wonder how they did it, this tolerance has been worked to ever since.

Mr. Bamford asked if any equipment was available for detecting blowholes *before* machining.

Mr. Park said that cylinder block castings were subject to a water test at a comparatively low pressure of 40 lbs. per square inch. At one time the cylinder bores were checked. This, however, does not assist in detecting blowholes, and whilst blowholes are not visible from the outside casting, there does not appear to be any satisfactory way of detecting them other than "watching" for them during machining operations. As a point of interest the amount of scrap on the cylinder block line was two per cent., i.e., two castings scrapped per 100 finished cylinder blocks, and the line had been running at this scrap percentage for some considerable time.

Mr. Mills asked whether the two per cent. scrap in connection with cylinder block castings represented "material scrap" or "machine scrap."

Mr. Park replied that practically the whole of the scrap from the cylinder block was "material scrap."

Mr. Gilbert queried the ratio of inspection personnel as against direct production labour.

Mr. Park stated that in reply to this question generally, he would give the ratio at the present time, of one inspector to fifteen hourly

paid operators, including the receiving inspection department, which of course is not in the producing areas. The ratio of inspectors to operators varies according to the class of work being produced. For instance, in the gearbox division, the ratio of inspector to operators is one to 12.5, in the axle division one to 15, and in the engine division one to 11. In dealing with any new product, many of the early mistakes are due to errors in specification, and this is a matter which must be put right immediately it is detected.

Mr. Theobold stated that he had not noticed any mention of the process of balancing. He particularly referred to the balancing of crankshafts and flywheels, and imagined that in these modern production days, there might be some very interesting equipment for this purpose.

Mr. Park replied that crankshafts are balanced on Gisholt machines, which indicate the amount of unbalance and the point of unbalance. It is quite a simple process to remove the crankshaft from the machine, machine where necessary to correct unbalance, and " try again " on the balancing machine. In the case of flywheels these are balanced on Gisholt *static* balancing machines, after which the flywheel is assembled to the crankshaft and clutch, and checked for static balance on knife edges. Any component not in running balance dynamically is not in static balance, and is therefore corrected.

Mr. Gilbert stated that a static check on balance is sometimes regarded as being not at all accurate, but if given a little thought, and provided that any " long " component in an assembly has been dynamically balanced and then statically checked, then that must be accepted as a sound check. A long article in dynamic balance must necessarily be in static balance.

Mr. Theobold mentioned that during the lecture, Mr. Park had referred to that class of inspection known as " visual " inspection. Many years ago, he was responsible for the checking of components for heavy vehicles, and he considered the most important part of this function was the inspection of such parts as chassis frames and members, pressings, and those parts which were not machined. It was realized that it was very important to check for cracks or any other defect which would give one an indication of early failure, and considerable time was spent in an endeavour to check every part successfully. He wondered whether any improvements had been made for dealing with this class of inspection at the present time.

Mr. Park replied that the preliminary inspection methods are very much the same to-day. He explained the method of early checks on such items as axle shafts, steering arms, etc. Such stampings are of course very important, and if in any doubt at all, the safest way to find a crack in a stamping is to soak in acid,

allow to dry and check again immediately afterwards. In checking stampings for cracks, this is done entirely visually, no special apparatus being used. The effect of the acid on the stamping is that it etches the surface of the stamping, and a crack is revealed by a mark of rusty appearance following the line of the crack.

Mr. Brook referred to Mr. Park's explanation as regards "etching" and stated that his company adopted this process rather extensively for checking grinding. He added that in grinding components under present-day mass production methods, the operation is performed at such a rate that cracks develop during the grinding process. The method for checking for cracks is the use of sludge from the grinding machines themselves—which is a dirty looking paste—mixed with petrol, which is brushed on to the grinding surface. By this process, and with the aid of a microscope, it is possible to detect cracks which are not visible to the naked eye. This mixture, under the microscope reveals grinding cracks almost like pencil lines. Their depth although serious, is rarely more than .0005 inch, and by grinding that amount away, it is possible to completely eliminate the cracks.

Mr. Park said that he had not found it necessary to use this process. It had been a long time since he saw a grinding crack. He imagined such cracks to be due to faulty machining. The floor inspector is the man who is trying to " catch " these faults at the correct point. He was interested to hear of this process, and would give it consideration to see if any use might be made of it.

Mr. Ronald stated that if the proper grit and grade of grinding wheel is used, no trouble should be experienced as regards grinding cracks. If your are grinding high speed steel with an unsuitable wheel, you will inevitably get cracks, and laminations which peel off like skin. These troubles are entirely due to incorrect type of grinding wheel and speed. Case-hardened steel is rather more difficult. It is essential to use not only correct type of grinding and the correct feed and speed, but also, under certain circumstances, the correct diameter of grinding wheel, because " contact " plays a big part in preserving case-hardened steel from cracks. In dealing with production under modern conditions, and with proper knowledge, it is absolutely bad workmanship and bad management to have grinding cracks in steel.

Mr. Brook pointed out that he was particularly interested in nickel chrome steel. He agreed that as regards grinding cracks, feeds and speeds had a lot to do with it, and of course there are certain instances when this trouble can be traced to the carelessness of the operator. There is very little trouble when the operation is performed with an automatic feed throughout, but where there is an indicator running on the work, that is where we sometimes get carelessness on the part of operator himself.

Mr. MacDonald referred to the work done on the blanched surface grinders, and stated that he was quite convinced that most of the cracks due to surface grinding were definitely the result of carelessness on the part of the operator.

Mr. Ronald conveyed the thanks of the meeting to Mr. Park for his excellent lecture, which had been most interesting.

Discussion, Western Section.

MR. WHITEHEAD (Section President): There is only one question I should like to ask the lecturer and that is, are the inspection department in his factory paid a flat rate only, or do they receive any bonus?

MR. PARK: Inspectors are paid a high flat rate. They do not get any bonus. We are trying to work out a scheme to pay them a bonus, but at the present time we are paying a high flat rate only. This is 1s. 6½d. to 1s. 9d. per hour for bench inspectors, and 1s. 9d. to 2s. 0d. for floor inspectors.

MR. KENWORTHY: Inspection generally, I think, is looked upon as a necessary evil, but it could and should be, of real assistance to production. Unfortunately, it is often looked upon as a stumbling block to production, but where assembly is in existence as distinct from fitting it is very essential that components should emerge from the machining stages correct to drawing to ensure correct assembly and also interchangeability. The primary object of an inspection department should be to prevent scrap, but unfortunately some of the people engaged on inspection consider that the more parts they reject, the better they are doing their job. On the other hand many production people think if they can get doubtful parts through the inspection they are doing their job. What the lecturer says of the material movement form would indicate that components cannot be transferred to subsequent operations until the material movement form has been filled in and signed by the inspector, and that all movement of material is controlled by the inspection department. This is very desirable but I cannot quite see how it could be carried out under line production. On line production it is usual for several operations to be carried out simultaneously. Mr. Parks says that on checking an operation those parts which are checked are segregated as correct. It seems to me that there is a tremendous amount of trust put in the operators in assuming that this is the case. It would be interesting to know the percentage of inspection personnel to production personnel which is considered necessary under the system which Mr. Park has outlined. I have just one other point; I notice that the company with which Mr. Park is asociated is no different from any other company in the number of drawing alterations they put through. I notice on the drawing of the connecting rod, which has been issued to the meeting, that during 1933 no fewer than 14 alterations were put through. It seems to me that this is a very general experience in the engineering industry.

Mr. Park: Mr. Kenworthy is right, the material movement forms are not used on line production. Where lines or conveyors are used the movement forms are not used. Material movement forms are used where items are not on lines or conveyors either for assembly or machining. Of course the majority of items are not on lines, and where they are not the movement form has to be properly filled in and signed before the material can be moved. As to identifying parts which may be faulty since the last component was checked by the floor inspector, this is done in various ways, but perhaps the best check is that we know roughly what the production per hour is, and we have to make certain we do check everything even at the expense of going further back than is absolutely necessary. This is the responsibility of the floor inspector, but in addition the whole of the batch is checked by the bench inspector. The ratio of inspectors to hourly paid in the Vauxhall works is one inspector to 15 men, that is hourly paid men who are producing parts and does not include any non-productive men. We have just about 200 inspectors and just over 3,000 hourly paid production men, out of a total of 5,000 employees. This ratio varies in the different departments; in some it is higher and in some lower. In the engine shop it is about one to 10, and in others one to 16 or 17, and in some even one to 30 to 40.

Mr. Mawer: Would Mr. Park kindly tell me what they do to obtain inspectors. Do they promote the best machinists or operators, or do they find it better to train apprentices specially for this work?

Mr. Park: We get our inspectors from anywhere we can. We get any amount of applications from good men, and generally we like to get men who have served an apprenticeship and are technically trained. Other times we take men from production. Our production men earn good bonus, so that we take them and put them on a flat rate we have to pay them a rate high enough to compensate them. We obtain good intelligent men and train them for a week or two weeks, however long may be necessary. We do not take chances. It is quite remarkable how much money you can spend by getting faulty material or faulty workmanship out into the hands of the public. Apart from the intangible cost of getting ones reputation damaged, once faulty products go out to the public, it costs a lot of money to put things right.

Mr. Williams: Mr. Park mentioned that each department manager was asked to prepare a budget. Is the manager of the inspection department also asked to prepare one? Is the inspection department charged for parts which go through which the inspectors should have found out? Another point which Mr. Park mentions is floor inspection, but he does not mention any method by which they inspect flaws. Mr. Kenworthy mentioned, but I would also

like to emphasise that in the early stages of the paper Mr. Park said that the movement of material was part of the responsibility of the inspection department. Is this accurate, because if so it does not seem to follow accepted practice ? Mr. Park also mentioned that the inspection department are not responsible for the finish and accuracy of the work. That might be applicable to accuracy but what about finish ? Don't they determine what standard of finish is to be adopted ? We have amongst us some production engineers, who work in an industry where the standard of finish has to be absolutely the best, but in the automobile industry there could be a range of finishes which while not absolutely the best would be quite suitable for certain jobs. Do not the inspection department determine what the standard of finish is to be ? There is another point, which while not relative to the actual inspection of parts, would, I think be rather interesting—how are inspection costs allocated ? Are they put down as part of the shop charges, or are they made part of the actual production costs ? I have one further point : in producing gears there seems to be quite a lot of time spent prior to hardening in determining accuracy. Is that not rather wasted owing to distortion, and would it not be cheaper to instal grinding plant and grind after hardening, and so cut out a lot of work prior to hardening.

Mr. Park : The inspection department have to make out a budget just the same as any other department. It usually takes us about a fortnight to do this. The complete works budget is made out in this way. The sales department first of all say how many of the various products they expect to be able to sell next year. We know approximately how many production hours will be required to do this, and approximately how much material and the value of the material that will go into that amount of the various products, therefore we can work back and see what the income is going to be. The inspection budget takes into consideration every bit of expense which the inspection department is expected to incur and is based on previous experience. A proportion of the income from sales is allocated to cover every manufacturing function and expense. Inspection is treated as a manufacturing expense, such as engineering, or plant maintenance, as distinct from direct production labour or direct production material.

With regard to inspection for flaws, this is almost solely visual until we find something which is not right, then we usually treat with acid and check immediately afterwards. With regard to the movement of material, as I said, when this is not on line production, it is moved by the transport department but the material movement form must have been completed by the inspection department. With regard to standards of accuracy and finish I do not think I said the inspection department have no responsibility in regard to

accuracy. There is a saying in our works which I think may be applied elsewhere, "When things are going badly, inspection is bad, when things are going well, production is doing a good job." Hardly a week passes but someone says something like this to me: "The inspection in our shop is not worth a damn, we have scrapped 24 camshafts, I do not know what the devil that floor inspector was doing." I agree that the frequency of the floor inspection check should have prevented such a large amount of scrap and steps are at once taken to prevent a recurrence, but I also point out that the production operators are provided with gauges and that they have the responsibility to produce good parts. The inspection responsibility is to help them to do so by checking material and finished components and finding out the cause of troubles when they arise and preventing defective material or parts from being assembled into our products and passed on to the public. With regard to the standard of finish, that is controlled entirely by inspection department, when I say "controlled" I do not mean that the standard of finish is "set up" by the inspection department. Standards are set up by quite a lot of people. The administration, engineering, sales, production, and other departments all contribute to settle standards of finish and when these standards have been set, it is the responsibility of the inspection department to see that they are maintained. Finish is a very controversial thing, for instance the paint shop is not in the control of the man who makes the bodies, and they complain that they cannot give as good a finish as they would like because the finish on the work they get is not good enough, and in turn the body builders complain about the press shop, and say they cannot build their bodies in the standard time because they have to spend so much time finishing off the work the press shop ought to do and so on, and we have a certain amount of internal competition and complaints running all the time.

With regard to gear teeth, we have had a lot of experience with gear teeth grinding over a number of years, but dropped it two years ago as we found it expensive and we did not get quieter gears, in spite of the distortion with hardening. On spur tooth gears we control distortion by careful heat treatment. Burnishing does not correct any distortion caused by hardening it merely irons out any little burrs which come about from handling.

MR. SAVILLE: I notice you use a system of putting the forging or stamping on the same drawing. You do not have a separate stamping drawing. I also notice you use the method of coin pressing. I have seen something of this system before. It is also used, I understand, for malleable iron castings and there is a lot of controvery about it. In one case I know of they usually do this coining cold. Do you do it cold or do you reheat before coining?

One further point is in the case of a rod like the connecting rod you show, it is quite simple to give a definite dimension for thickness of boss, but suppose the dies were split in the opposite way and the draft was on the side of the boss you would get a definite hump in the middle. If you had stampings from two different firms would there not be a danger that one stamper would split the dies through the boss in one way, and the other in the opposite way, and therefore the stampings from the two firms would have different dimensions in the middle. How would inspection deal with jobs of that nature ? Have you had any trouble with malleable iron components cracking due to too much squeezing ?

MR. PARK : The coining in our works is done cold always, we take pains to point out to the suppliers just how we want our jobs stamped, and they have to make their dies to suit.

We explain to our stampers how we propose to machine them and they explain and agree with us how they are going to stamp them. We do coin malleable castings as well sometimes, but not very often, and, of course, you can get cracks from too much coining. You will see we maintain our stampings within very close limits, as if you get too much metal you cannot coin within the necessary, close limits. You have got to control the amount of material in order to get satisfactory results from coining.

MR. HIGGINS : One of Mr. Williams' questions reminds me of an occurrence which came to my notice during the war period. A batch of crankshafts was sent to the fitting shop to have a 2BA. hole tapped in the web. The fitter found the hole to be undersize, but managed to tap two shafts successfully, breaking the tap in the third. The question I would put is, who was responsible for the scrap ; was it the driller for drilling an undersize hole, the inspector for passing it, or the fitter for breaking the tap ? I wrote the shaft off as being due to " an act of Providence," but unfortunately the works manager did not concur.

MR. PARK : Unfortunately that is the kind of thing that does arise which cannot be satisfactorily dealt with. We often get cases like cars on the body line found with broken glass and nobody will accept responsibility. We charge anything found defective about which there is any doubt to the man in whose area it is found. Of course a man will often say " It came to me like that," but even so he usually has to accept responsibility.

MR. NOLAN : I think you said that where agreement cannot be reached between production and inspection, the word of the inspection department is final. I would like to ask whether the design people are brought in, and also whether there is any salvage scheme which carries on after a decision has been given.

MR. PARK : Yes. The engineering department are consulted regarding the possible reworking of defective parts and at times

when a small increase in the drawing tolerances would save a lot of material. When the normal tolerances are stretched a little under special circumstances, we term these special salvage limits. Requests for salvage limits, however, are not encouraged.

MR. FOSTER: Could the lecturer explain a little more fully the grading he spoke about on the front axle.

MR. PARK: We grade these because of the variation which occurs in the forged length which in some cases is up to 3/16. A machine is set up and we drill the two pivot pin and four holes in the spring pads at the same time and because of the variation in the forged length the axles are graded into three grades and the machine is set up to suit each grade.

MR. WILLIAMS: Mr. Park states in his replies that they were anticipating bringing in an incentive scheme for the viewers. I should be very pleased to know what method they intend using. Obviously you cannot pay a man for the time he takes to do a job, because if you do he would pass it through and perhaps pass defective work. Can you give me some idea as to the suggested method.

MR. PARK: I am sorry I cannot give any details of the methods which have been considered.

MR. KENWORTHY: I saw one slide which Mr. Park showed where he said that they do not do any reaming of the main bearing lines in the crankcase. I would like to know whether this is the generally accepted practice in the industry nowadays, to bore the holes for the main bearings accurately and put in the liners without any further reaming.

MR. PARK: This is at least common practice. The crankcase bores are held to a tolerance of .0005 inch. The liners to .00025 inch wall thickness and .0005 inch on the half length under a pressure sufficient to hold them firmly in a fixture of the shape and size of the case or cap into which they will be fitted.

The crankshaft journals have a tolerance of $\pm$.0005 inch and with this combination the bearing clearances are a minimum of .001 inch and a maximum of .003 inch.

A cordial vote of thanks to the lecturer concluded the proceedings.

THE COST OF FINE ACCURACY.

Paper presented to the Institution, Glasgow Section, by L. Clayton, M.I.P.E.

I SUPPOSE it is reasonable to say that the range of tolerances or limits imposed by the designer in medium size engineering to-day lies between .001 and .005 inch. There are, of course, a considerable number of units which are built to wider limits, say .005 to .010 inch, and not a few have to be machined to an accuracy of plus or minus .00025 inch, these latter usually being parts which are hardened and ground. Still speaking of medium size engineering, in which category we may include practically all components used in the manufacture of motor cars, printing machinery, textile machinery, and indeed the vast majority of engineering components weighing not more than four cwts., I would say that a survey of the gauges used leads one to doubt whether the conditions of accuracy envisaged by the designer are always realised in practice. Coming to light engineering, tolerances are smaller, the average probably being plus or minus .000375 inch ; very many of them being plus or minus .00025 inch and not a few plus or minus .0002 inch, so that, taking the situation as a whole, we are justified in saying that the average engineer to-day produces work to fine limits of accuracy.

There has, however, come into existence during the last few years a number of types of light engineering in which components are made in large quantities on a production basis to a limit or tolerance which may be anything from plus or minus .00015 to plus or minus .00001 inch. These limits may possibly seem rather startling and one may be tempted to reflect that, whilst there may be some unique component thus produced, the matter is one which is likely to rest there. Such an assumption is not, however, supported by the facts, since the list of mechanisms or apparatus demanding such accuracy and employing such tolerances is growing steadily and to-day includes parts used in the manufacture of internal combustion engines, printing machinery pumps, projection apparatus, refrigerators, and much else besides. It is not unreasonable, therefore, to suppose that engineering concerns both large and small may, during the next few years, have to take cognisance of this tendency to scale down manufacturing tolerances. Indeed, arrangements are already being made for a large scale extension of this class of manufacture in Great Britain. In some cases these limits

are imposed in order to make possible interchangeability of parts and to secure low cost assembly, but in very many instances functional requirements have compelled the imposition of these ultra-fine limits. For instance, the advent of the sound film made it essential that the sprocket wheels for feeding the film should be made to a limit of plus or minus .0001 inch as to pitch of teeth, otherwise musical notes of a pitch higher than five thousand frequencies per second were lacking in fidelity and unpleasant to the ear. In the near future we shall begin to realise, perhaps under the stress of competition, the great advantages that accrue from the use of interchangeability. These advantages are many ; it has been estimated that the cost of assembly can be reduced by nine-tenths by abolishing fitting and substituting for it a system of interchangeable manufacture, so that each part fits accurately into its allotted place in the complete mechanism, just as it comes from the machine. There is much to be said on behalf of this system of manufacture. Besides reducing cost of assembly, it can be expected to increase sales through enhanced quality of product and to improve the service which the manufacturer renders to the user of his goods, because it reduces the chance of a replace part proving to be a misfit and so being a cause of irritation and loss of goodwill to the maker. Another advantage is that the stock of spare parts carried by service depots or agents need not be as large as is the case when a system of selective assembly is used. Further, the labour charge for fitting of spare parts is reduced because less time is used in fitting and unskilled help can be used to a greater extent. Probably, however, the most potent factor in bringing ultra-fine limits into the sphere of practical politics will be the ever increasing competition of quality ; the clamant demand of a public insatiable in its desire for more and better value for its money. For these reasons it seems to me to be unnecessary to spend a great deal of time in considering the question of the " cost " of fine accuracy, and better that we should bend our energy and attention to the quest of it. The American Society of Mechanical Engineers have lately made an inquiry into this matter of the cost of accuracy as applied to grinding. They state that if the cost of obtaining a limit of accuracy by grinding, of the order of .0005 inch be unity, then the cost of reaching .0004 inch would probably be 1.2, of reaching .0003 1.375, .0002 2, .0001 3.66, and the cost of reaching a limit of half a ten thousandth probably 5.33. With regard to these figures, I would observe that when one goes below a limit of a quarter of a thousandth one leaves the realm of grinding and enters that of lapping and, that being done, the cost at once falls again and becomes quite nominal. Indeed, the cost of the accuracy of half of a tenth of a thousandth and less, which obtains to-day in the classes of manufacture already mentioned is very low, due to the fact that they are

achieved through the medium of the process known as mechanical lapping to which they happen to lend themselves very admirably. Unfortunately, this process is somewhat limited in its field at present. Indeed, until the appearance of the bonded abrasive disc the lapping of unhardened parts was attended with difficulty owing to the risk of the work becoming charged and, in turn, damaging contacting faces after assembly.

What we have to consider is the problem of producing complex surfaces to limits certainly not greater than plus or minus .0001 inch in soft materials by means of cutting edges of steel, tungsten-carbide or diamond. Considerable progress has been made in this direction but before coming to that we will consider for a few minutes, the possibilities of our present machine tools with reference to manufacturing tolerances. It may be observed of some manufacturers that they are already, in some cases, claiming an accuracy in the boring of holes on a mass production basis of a limit of plus or minus .00005, which claim is worthy of further attention. Taking the statement at its face value it means that every hole is literally and positively either one inch diameter or some diameter between one inch and 1.00001 inch diameter, not, I would ask you to remark either .99995 inch nor 1.00015 inch, but strictly within the dimensions first mentioned, and we are to understand that many thousands of holes are bored each week and that each hole will admit, in a proper manner, a gauge of a certain size and will not admit another .00005 inch larger even for a short distance. What can be the limit on parallelism or roundness in such a case, remembering that the limit so placed must be less than the .0001 already specified for diameter. Further, who is to decide the amount of pressure that can be legitimately applied to the " go " end because, if pressure is necessary, it is more than likely that the limit is infringed at that end. We must remember the constant tendency of the workman to keep holes as small as possible in order to avoid producing an oversized hole. No two holes are ever alike. We are not considering lapped holes in hardened material, but in soft metal capable of being cut with a steel tool.

Similarly, we have the manufacturer who says all his threaded products are made to a tolerance of .00035 inch. Here it is necessary to consider that there are seven elements in a screw thread and that the National Physical Laboratory will give their highest class certificate of accuracy to a screw plug gauge that is within a general limit of .0006 inch. The mere gauging of parts to minute limits such as those claimed constitutes a problem of no little difficulty. I suppose a certain amount of exaggeration is to be expected in a manufacturer's estimate of the value and excellence of his own wares, but it is quite impossible to machine large quantities of components to a tolerance of .0001 inch, or, in the case of

screwed components, to a tolerance of less than .0005 inch.

The possibility of producing to ultra-fine limits is, at the moment, almost entirely confined to hardened work and to one process, namely mechanical lapping, and in considering any extension of this sphere it becomes necessary for us to take stock of our present facilities and their possibilities as well as our prospects for the near future. I have been looking into the tolerances used by makers of high grade machine tools; not so much tools for general production in the shops but for tool room and mechanical laboratory use, and I find that in general, three classes of limits are used, which may be graded as fine, medium, and ordinary. If a seven-eighths diameter shaft were being gauged in each of these three grades, the limits imposed would be .000436, .00059, and .0017 inch, respectively. I found that one famous maker of machine tools of this class imposes a limit of .0001 inch for concentricity of the various diameters on a hardened, ground and lapped spindle, and in the case of a splined shaft four feet long, the gauge showed a tolerance of .004 inch in the length given for parallelism of spline to axis of shaft. The limits mentioned are for work in unhardened steel; quantity production methods do not obtain and there is a considerable amount of hand work involved. Interchangeability is not the aim of the organisation.

Leaving this class of production with its limited output and its craftsmanship, we come to our real problem, which is to produce in medium or large quantities to a limit of plus or minus .0001 inch. We have to bore holes and ream or grind or hone them. We have to locate these holes in certain specified positions. We have to machine faces, sometimes simple, sometimes complex, by means of planing, milling, shaping or broaching machines and we have to machine external cylindrical surfaces by means of turning or grinding processes. If we are dealing with large quantities of parts some of these operations may be performed more or less simultaneously as on the automatic screw, or chucking machine for instance.

What degree of accuracy is obtainable to-day from machines of this type? The best of them, equipped with special tools, can turn external diameters to a tolerance of .00075 inch and keep it up all day if they are well handled. Turret tools, with the same provisos can maintain lengths to a tolerance of .0025 inch. Where the length is such that it can be controlled by a full figure form-tool mounted on a cross slide, this figure can be reduced to .0015 inch. Rather wider limits are necessary in the case of multi spindle machines where the maintenance of concentricity between different diameters is apt to be a matter of some difficulty. A very large percentage of the better class of screws are made on auto-screw machines to a tolerance of .001 inch. In spite of the popularity of the self-opening

die-head most screws are threaded by means of button dies and to work to the limits stated these require to be of a quality superior to those usually purchasable to-day. You will be correct in assuming that the production of screw threads to ultra-fine limits, is at present impossible, at any rate commercially, and ground threads are out of the question on the same score. Personally, I look to the cold rolling process as a potential method of producing screw threads to a much greater degree of size consistency in the near future, in its present state of development this process gives a beautiful thread form and pitch accuracy is such that micrometer screws are being finished by this means. So far as screws are concerned accurate thread rolling is bound up with the problem of cold drawing wire to a limit of plus or minus .0001 inch, but this, given a sustained demand, will probably be not too difficult in these days of tungsten-carbide drawing dies.

As with screws, so with nuts; 90 per cent. of all internal threads are cut by taps; here again it is quite impossible to produce screwed holes in large quantities to fine limits on a commercial basis. The ground thread tap can be as accurate as you wish but its accuracy is not altogether reflected in its performance. I have seen holes of widely differing accuracy, or lack of it, cut by the same tap used both in a machine and by a fitter as a hand tap. It is perhaps fortunate that the majority of screw threads are used only as fastenings.

The sizing of plain holes of small or moderate diameter is mostly the province of the reamer, a tool, regarding which, I feel compelled to say of the purchased variety, that it is not a precision tool at all, viewed in the light of present-day standards, much less an ultra-precision tool the need for which we are now contemplating. Bought reamers require a tolerance of at least plus or minus .001 inch, but it is not a difficult matter to produce reamers of a much finer quality, and there are many thousands of instances where reamers are made to work to a limit of plus or minus .00025 inch and sometimes less. Of course, the life of a reamer working to these limits is shorter than that of the bought variety already referred to, but the cost, on that account is not prohibitive. The problem for which there has, as yet, been no solution, is to produce a reamer which will give a really high grade finish in machine steel, a finish comparable with the so-called "mirror" finish produced by honing. This will be done, however; perhaps tungsten-carbide will prove to be the solution and there are other possibilities so, altogether, we need not regard the production of high-grade plain holes in cast iron or steel, to a limit of plus or minus .0001 inch as a major commercial or mechanical difficulty.

The milling machine and the milling cutter are very hard worked members of the metal cutting fraternity to-day. A very great

many plain and complex surfaces are finished by this process, but it is a little difficult to visualise a rotating multi-tooth cutter of this type being used for the purpose of finishing surfaces to limits of the order of plus or minus .0001 inch. Due partly to the design of the machine and partly to the nature of the cutter itself, there is always a more or less minute undulation of the finished surface. Probably this question of finish on milling operations will come in for a lot of attention and research with a view to improvement because the milling cutter is a very cheap stock remover. It has been estimated that a good milling cutter will remove 1,000 cubic inches of cast iron for every halfpenny invested in blades, not counting the cost of regrinding, but the disability just mentioned, due to the fact that the teeth which remove the bulk of the material are also responsible for the finish, is for the present a decided obstacle and one which is common to all cutting edges which have to rough out as well as finish. From the milling cutter to the broach is a natural step. In this case certain teeth are reserved for finishing and are given very little work to do, as a result of which some very remarkable figures as to close limits obtained by this process are being quoted. Limits of the order of plus or minus .00015 inch, for instance. When one comes to think of it there is every likelihood that a tool of this type will produce work to very fine limits indeed, particularly the latest development of it, the surface broaching machine, in several current designs of which, the broach remains stationary whilst the work is carried past the cutting edges in jigs fastened to an endless chain. The broach itself is built up from a series of short sections ; should one section become damaged the entire broach is not thereby ruined. Also, as the broach wears, it can be replaced, a section at a time, those which were the finishing sections being moved into an earlier or roughing position after the teeth have been reduced in height by an appropriate amount. New sections of broach are placed in the finishing position. This type of machine, cutting at a rate of 25 surface feet per minute, produces 1,800 finished pieces per hour, removes $\frac{1}{16}$-inch of stock from connecting rod caps and has a life between grinds, of fifty thousand parts. Thus we have here a tool with distinct possibilities in the sphere of ultra-fine limits.

Another tool with great possibilities in the same direction is the modern electrically controlled die sinking machine. The accuracy of this machine in its present state is such that a movement of .001 inch on the part of the stylus or tracer point is reproduced accurately by the cutting tool on the work. Further development of this machine will probably be directed to the improvement of the finish of the machined surface. Electrical control of cutting edges which has been mentioned in connection with the machine just noticed, is full of potentialities in connection

with the accurate location of finished surfaces. It is hardly fantastic to suppose that such control, through the medium of the photo-electric cell and the thermionic valve will be capable of very wide adoption, and may possibly be one of the keys to a much greater degree of accuracy and control in metal cutting. It is not difficult to visualise a group of automatic machines each engaged on the manufacture of the same part and controlled from a small cabinet wherein may be master cams, protected from dirt and atmosphere and finished to a degree of accuracy impossible to-day on full-sized cams on the machine itself.

Another machine which is quite new and in one respect unique, is a continuous miller of the planetary type with six vertical spindles, scheduled to produce 12 pieces of work per minute. The maker of this machine guarantees that the work produced will be accurate within a limit of plus or minus .00025 inch. This machine, which is of the station type, is interesting, not merely because of the guarantee which goes with it, but because it apparently does not sacrifice accuracy to complexity but maintains it in a fashion and to a degree most unusual in machines of the complex kind of which it is a specimen.

Still thinking in terms of very fine limits, it is interesting to know that a British firm are now putting out a new centreless grinder which they guarantee will produce work, either straight through or shouldered, to a tolerance of .00025 inch on diameter and I understand the roundness or circularity of the work is such as to permit it to be lapped by mechanical methods.

A good deal of research has been made during the last two years into the art of accurately finishing internal cylindrical surfaces in cast iron and unhardened steel, and machines have been constructed in several countries for this purpose which, it is not improbable, will prove to be the first practical machines to be made for the purpose of cutting metals to a limit of plus or minus .0001 inch. Based on the fact that honing, which is really a rough lapping process, requires a very accurate hole in the first place, the designers of the machines in question have decided that it is cheaper to go the rest of the distance and produce a hole of such quality as to render honing superfluous. Recognising that up to the present all methods of boring have built up a strong and deleterious cutting pressure, and that grinding by means of a revolving abrasive wheel does not give very satisfactory results on unhardened metal, these machines go back to the old method of rotating a single edge cutting tool at a high speed with an extremely minute depth of cut and feed per revolution. By these means, using a cutting edge of diamond or cemented carbide, holes are being bored to a limit of plus or

minus .0001 inch with a reflecting surface. Bearings finished on these machines are said to make 100 per cent. contact with a lapped journal. The drive is by means of silken belts, spliced, and belt pull is taken by independent bearings which relieve the tool spindle of all strain.

In the same class as the machine just noticed is a German vertical fine boring machine with three spindles, developed for finishing the bores of petrol or other engine cylinders and eliminating the necessity for rolling, honing, etc. This machine which is a practical production tool, will bore cylinders of 1.5 to 4.7 inches in diameter and 9.8 inch stroke to an accuracy of plus or minus .00015 inch for size, roundness, and parallelism of bore. The spindles of all the machines of this type are ground and lapped.

I sincerely hope this list of machine tools has not proved too tedious. It is given with the idea of demonstrating that the day of finer tolerances is not a vision of some very distant era yet to come, but is imminent and that its imminence is being recognised in the machine tool world. It is, further, a sign that the real difficulty of the situation, namely, the accurate location of surfaces in soft metals is recognised and is receiving attention. As regards hardened work, within limits this presents no problem at all, the only limit to accuracy in that field is placed upon it by the measuring tools at our disposal.

Our search for fine accuracy will be productive of a good many changes in machine tool design in the near future. There are all sorts of possibilities ; firms are already using the stronger, more stable, easily machinable cast irons of the Mehanite and Nichrome variety, and artificial ageing or seasoning is already resorted to in order to impart stability to the structures. Steel faced iron and nitrided steels are also being made use of to impart durability to wearing surfaces. Anti-friction bearings seem to be conspicuous by their absence in such fine limit machines as have so far appeared for cutting soft metals. Great pains are being taken to eliminate transient interferences such as might occur in certain conditions, due to belt fasteners or to variation in resistance offered by the substance of which the belt is made, and you will have noticed that in some of the machines mentioned silk is being made use of because of its strength, pliability, and consistency. Much more material is being put into machine tools to-day, not merely because of the greater strains imposed by heavy cuts, but in order to give permanence and stability to machines or portion of machines designed to impart finish and accuracy to the work. In this connection it is perhaps satisfactory to reflect that this tendency is a departure from the light weight theory propagated in America and a return to the more substantial products which we initiated and grew resigned to hearing derided. The distribution of the mass is probably

more on scientific lines but it shows none the less, that our early designers were not so wide of the mark as has been thought.

In connection with machine tool design, it has always seemed strange to me that the cylinder has not been made greater use of by designers for such parts as beds of machines or cross slides or indeed almost any foundation upon which some other part of the machine must move or slide and I offer the suggestion that this form of construction has much to commend it ; ease of manufacture for instance, and the extreme accuracy to which it can be produced. It can be made in steel, hardened, ground, and lapped to a finish and accuracy only limited by the instruments available for checking it. I designed a machine some years ago embodying a sliding headstock and made use of a pair of cylindrical steel bars as ways instead of the usual vee or flat bed form and found it infinitely cheaper. Incidentally I remember the surprise of the person who ground the bars when he found his supposedly superfine grinding finish resolve itself into a series of hills and dales under the action of the lap. I ask you to visualise a machine in which all slides are composed of well supported cylinders lapped to a degree of optical perfection. You would, I suggest, come much nearer to the ideal of a perfectly straight line motion. Machine tools embodying this form of construction would probably cost not more since lapping, while capable of producing a surface of exquisite finish and accuracy, is not an expensive process and is certainly much cheaper than scraping, for instance. Incidentally, it is not out of place to mention, in connection with the lapping of cylinders, that a British firm has just secured a patent for a process to impart absolute optical perfection, both as regards finish and accuracy to cylindrical forms up to many feet in length and diameter. In fact they are applying it to rolls used for finishing sheet metal and I have no doubt that later its application will be extended. I have not mentioned the matter of dynamic balance as an item in our list of requirements since the need is one which is already quite well recognised.

There are other factors which are worthy of consideration in connection with our quest for fine accuracy. The design of metal cutting machine tools does not cover the whole of the possibilities in this direction. The design of the product, or the components constituting the product will be scrutinised with a view to facilitating its manufacture to much finer limits of accuracy. Complicated forgings or castings may be found to be capable of dissection, this process making accessible for the purpose of fine machining and measurement, faces, holes, bosses, or other projections which, always susceptible to functional improvement by this means, were previously debarred from it by reason of their position.

This possibility springs from the use of the expansion fit process which a number of companies are now using on a production basis

and in which one of two members which it is desired to permanently assemble to another without recourse to threads or other fastenings is immersed in liquid air or in carbon dioxide which cause a shrinkage of the part, permitting it to be placed in position whilst cool. When so placed, expansion commences and the part is permanently assembled. A further and obvious development has been to place one member in boiling water until it attains a temperature of 212 degrees Fah., this is in addition to placing the member to be inserted in liquid air; thus is the difference in size between the parts increased.

This process offers many advantages besides simplifying the machining to fine limits of parts which previously could not be so treated; it has all the strength of the old style shrink fit but does not damage the faces concerned. It is of value in cases where one part of an assembly is to be hard whilst another requires to be left soft. In this case, the part would be re-designed as two components.

To go into details with regard to this process is rather outside the scope of this paper, but information regarding the temporary changes in size of materials used can be obtained from such firms as the British Oxygen Co., the process is simple and clean, and provides an easy method of permanent assembly. Where one part is bulky and one small, the expansion method is used; where both parts are small the combination of expansion and contraction can be used. It is necessary to so adjust the sizes of the parts before treatment that the elastic limit of the materials is not exceeded in assembly otherwise a permanent set may be created. In the same way the ultimate strength of the material must be watched in order to avoid fracture. In regard to the strength of the joint, I may say that a load of 6,000 lbs. is required to force a one inch plug from a hole into which it had been assembled by this method.

At the commencement of this paper, mechanical lapping was referred to in connection with quantity production of component parts. Until recently, lapping has been regarded as a process used exclusively in the manufacture of gauges; this phase has passed and to-day mechanical lapping machines operated by unskilled labour are finishing parts in quantities at an absurdly low price to a degree of accuracy superior to all but the very best of gauges. Firms are to-day employing these machines in batteries up to 30 in number. In one case a firm is lapping pump heads and bodies for use in a domestic refrigerator; these parts are bolted together without a gasket, that is, steel to steel, but the joint must be proof against the passage of liquid air gas. Stellite valve seats are lapped to a limit of plus or minus .00005 inch for flatness and must have a surface utterly without blemish. In another case pump bodies are lapped to a limit of plus or minus .0001 inch for size and parallelism and flatness at the rate of 175 per hour per machine. In another

case gudgeon pins are finished to a guaranteed limit of plus or minus .00005 inch for diameter and parallelism at the rate of 140 per hour per machine.

Piston rings are lapped on both sides to an accuracy of .0001 inch at the rate of 720 per hour per machine. A firm making carburettors for Diesel engines are lapping parts at the rate of 72 per hour to a limit of plus or minus .00001 inch. The list of lapped parts in modern engineering is growing swiftly and includes anti-friction bearings, parts of electric motors, speedometers, pinion shafts, sides of inserted tooth gear cutters, sides of inserted blade thread chasers, linotype moulds, faces of flat gear cutters, and the faces of small gears. Also, at least one firm has begun to mechanically lap all its cylinder blocks and cylinder heads. Re-design of parts will, in conjunction with expansion fits, result in a very much wider exploitation of this very inexpensive means of attaining ultra-fine accuracy ; that it is inexpensive there can be no doubt. On the machines fitted with bonded abrasive discs a production of 500 piston pins per hour is being easily maintained day after day to limits of accuracy of plus or minus .00005 inch for diameter, circularity, and parallelism. There are at least two firms in Great Britain, one in America, and one in Germany producing machines for mechanically lapping flat or cylindrical work.

With regard to the operation of lapping, the only difficulty most people experience is in maintaining parallelism of the product. In this connection it is necessary to visualise what is happening to the work between the laps. The work is lying on the lower lap, each piece in a receptacle cut for it in a thin, circular work-holder. The pieces do not lie radial to the centre of the lap but tangential to a circle three inches diameter. In the machine using cast-iron laps, the bottom lap rotates and the top lap remains stationary, resting on the work. Since the bottom lap rotates both on its own axis and on another centre eccentric to its own, it follows that at every moment during the process, each part of every component being lapped is subjected to a cutting speed that is constantly varying, the eccentric motion, however, enables us to arrange that every part of every component received the same number of strokes at the same cutting speed. The eccentric motion also insures equal wear all over the lap. A dissertation on lapping is probably outside the scope of this paper, but one other point might be mentioned—users of this process soon discover that time is a quite reliable guide with reference to the size of the parts being lapped, so much so that one firm equip each of their lapping machines with a clock.

When working to limits of the order of .0001 inch it is obvious that some rapid, accurate, simple, and reliable instrument for measuring and comparing be available. Such an instrument is the

measuring machine which permits direct readings to .00001 to be made and readings of .000005 inch to be estimated.

In conclusion, I would like to say that the objection has been raised that in attempting to work to a limit of plus or minus .0001 inch trouble might develop with reference to changes of temperature. This is not so. A change of temperature of one degree Fah. would produce a change of size in a one inch cube of steel of .0000063 inch only. Even without the new standard temperature of 68 degrees international interchangeability would still be possible to the limit mentioned.

Discussion.

MR. MACFARLANE: The author mentions one firm in Germany on Diesel work using the tolerance of .00001 inch. I will not ask him how this firm claims to measure that great degree of accuracy under commercial conditions as here you have got to go to places like the N.P.L. to get any guarantee of anything finer than 1/100,000th of an inch. We ought to keep in mind that such measuring machines require very special treatment and are put up in special buildings on special foundations at special tempertures and proof against vibration. I was interested in the cinematograph machine. I know a firm who were faced with this trouble and they had to use optical means of testing to get the degree of accuracy. I think the trouble in that case is that you get undertones which seriously mar the hearing. I would say from my own experience that nine-tenths reduction in costs of fitting and assembling due to superfine accuracy is just rather optimistic. I would like to hear him give some expression as to the relationship between selective assembly and absolute interchangeability.

It is regrettable he has rather waived the question of costs which after all was the centre of gravity of the paper. He touched on the matter with regard to grinding and he gave us figures which seem to be reasonably accurate but it would have been interesting to have had a little more information on this side of the work. The only data otherwise given is he expects a big reduction in assembling costs and I think we would all be agreed on that. Then he goes on to mention increased sales through enhanced quality. That is open to question. I was in Birmingham in 1920 on special business and I was told by the largest firm of optical appliances that the majority of people would not face an increase in cost even though they were going to get 50 per cent. better article. That was based on fifty years' experience of the trade. As far as the reduction in spare parts stocks, I think everyone will agree on that.

We have the other side of the picture. We have got the increase in measuring cost. It may not be exceptionally high but we have got to meet the increased costing charges on capital outlay for accurate plant. Further there is the increased cost of inspection and repair of that plant. It will have to be inspected more often. You have got the increase of making and maintaining gauges to control the work and further the increased cost charges on the capital cost for precise measuring equipment in special buildings and increased cost of scrap

It was interesting to see some of these claims and when you come to analyse the difficulties it is remarkable that people can live up

to some of these claims in production. Take precision boring where he mentioned the tolerance of plus or minus of half of one-tenth thousandth inch. You have got the human variation in the setting up of the tools; the wear of the latter, and the whip and vibration of the machine structure. Then there is the variation in the structure of the material itself and temperature, and you have finally errors in your gauges. You have got permissible wear in gauges and the human factor in applying gauges and then the factor of the "go" gauge end. Possibly the only chance of living up to a tolerance of that restriction is by thread grinding or milling.

As far as familiar screw threads are concerned when you come to the smaller sizes I do not think there are gauges in existence or measuring instruments which will help you to get down to even half of one-tenth of a thousandth accuracy.

I was interested in what he said about milling. I think we have got to use tungsten-carbide more. Where small cutters are concerned I think the tool would have to be made out of tungsten-carbide. With regard to broaches I think an exceedingly fine tolerance would have to be placed on the external parts of the part to be broached.

I was interested in the multiple spindle miller for which it is claimed it will be accurate within a limit of plus or minus .00025 inch. Those who are familiar with the difficulty of taking a normal parallel part and gripping it in a parallel vice will realise in continuous milling with these spindles you are getting further complication of having seven different centres to make your possible of error seven fold.

Some time ago I heard that Fords were actually making their gudgeon pins to the tolerance of plus or minus one-tenth of a thousandth inch. A short while ago I spoke to the inspector at Dagenham and he said that was not actually the case, but they were using a form of selective assembly and they were selecting gudgeon pins in groups of one-ten thousandth each and assembled them in accordance with their size. I think a lot of these claims are somewhat exaggerated. The effect of aiming at high accuracy has had enormous effect on design of product. Where for instance you are using a slot for guide which may have been milled you have now got to go to entirely different construction such as a centre which has got to be ground and lapped to the order of one-ten thousandth.

Mr. Kirkwood: I think the question of fine accuracy should, in the first place, be concentrated on the machine tools so that we can produce not only accurate work but consistently accurate work. Most of us find that with great pains we can produce accurate work say to half a thousandth or one tenth, but the difficulty is that there are very few machine tools other than the lapping machines

which can produce that over a batch, and it is that lack of consistency which is so annoying. To get a real advance the machine-tool makers have got to give us tools which will produce to half a thousandth on fairly complex operations. With most of the claims we find from bitter experience they are exaggerated. One usually doubles the degree of inaccuracy and you are probably about right.

With regard to measurement, even such a simple part as a bore, to less than half a thousandth, I would say that the normal plug gauge is unsuitable in that, if the bore is slightly out of round, you simply do not gauge that bore properly. You need some instrument or gauge which is more sensitive so that you not only gauge the minor axis but are able to get the major as well.

Tolerances. On screw threads (dealing again with commercial accuracy which interests most of us) the B.E.S.A. standards have two different classes of threads—normal and close fit. It is almost impossible to buy commercial bolts of half inch to B.E.S.A. close fit in the open market at anything reasonable in price. That is a tolerance of 2½ thousandths of the effective diameter, not a question of one-tenth at all. We have a long way to go before we start talking about tenths.

In regard to finishing of bores by reamers to a mirror finish. Has the author any experience with the armament firms regarding rifling? I recall where the finish was regarded as unsatisfactory yet I would have called it almost a mirror finish. I believe it is produced by something after the fashion of a " D " drill.

I think most of us who have experience of the work being produced in the average machine shop will agree for consistency coupled with accuracy the centreless grinder is the machine which is most satisfactory. The figure of two-tenths tolerance was mentioned. I think any centreless grinder, properly operated, should be able to produce over a batch to that figure.

Regarding the question of temperature, I would join issue with him on the final paragraphs of his paper. I think while temperature can be neglected in the case of components made in iron and steel, many of us have to deal with other alloys where the rate of expansion is very different to the gauge and one has to watch very carefully the temperature of the shop. In dealing with parts of that nature you have to keep your shop at a constant temperature which is a difficulty for most of us.

MR. BUCHANAN: How are we going to hold the work to get these accurate sizes? I think even between centres on a simple spindle it is difficult to control them to get a 1/10,000th inch. With the ordinary spindles you can hardly get it. With the more complicated ones we must have something very accurate to hold them right. Is it possible to get that? Fuel pressure pumps. A few months

ago we had an inquiry from the people who are the biggest manufacturers in this country asking us if we would take on these jobs. We had no appliances and they were looking for someone to give them the accuracy required.

MR. WOOF : The author mentioned machine tools with cylindrical beds and cross bars. Whilst I agree it may be possible, what steps would he take to allow for reconditioning such machines ? Mr. Kirkwood more or less accuses the machine-tool maker of not being able to keep the work to close limits. I suggest the remarks should be pointed to the high-speed steel manufacturer. If it were possible to allow for roughing, finishing and sizing we could keep to finer limits. Fuel Pump.—We have someone up here making them and Simms Magneto people are also making them.

MR. RUSSELL : I think in the case of machine tools there are many items where the cylinder is ahead of any form of slide.

MR. MALLET : Mr. Clayton remarked upon milling machines. I am anxious to know if you are producing each part to quarter of a thousandth. The first stage would be rough and the second a finer cut so that the machine is being used for successive cuts. That has a bearing on the subject of costs of fine accuracy. Lapping machines. 1927 is the date when the abrasive lapping machine came into use which gave a very much greater production as regards the cast iron machine with very little increase in cost. It was only by substitutin an abrasive machine that you were able to get the parts off much more quickly. We have another instance of where accuracy is being obtained by the machine, the new Landis method of sizing from the machine is reputed to produce work to the same size continuously. You have not increased anything in the way of cost in the machine ; you simply apply a sensitive gauge to the machine which stops when the accuracy has been reached. With regard to circular parts for beds of machines, whilst it might be suitable for beds I cannot see how it would be suitable for cross bars. To take heavy cuts you have really got to support the bars at the end. Fuel pumps.—The best method I know of is diamond dust lapping.

MR. PATE : It seems to me extremely difficult to get common ground for the title of the paper, that is, " The Cost of Fine Accuracy." It has been rather a dissertation on the difficulty of getting accuracy. We did have some figures on costs which gave one the impression that as the accuracy increased so does the cost. It is a rough guide ; a very rough measurement. Naturally it is the cost which matters. We are not interested in accuracy for accuracy's sake, and I would have liked to have got a better picture of what is intended by accuracy. It is quite relative. The figure of one hundredth of a thousandth just leaves me cold not translated

in £ s. d. I am inclined to agree that the public have something to say about fine accuracy.

I would like to comment on the question of expressing fine accuracies. It is sometimes difficult to get an agreement. I would rather have all such figures as tolerances. I rather discourage in my day to day contacts talking about fancy figures. Not long ago I had occasion to question circular size of bore. It was not in very fine figures (we will put it in tenths). We discovered no two measurements were alike. Even when a size was given it only applied to a very restricted area. Lots of people give out figures, but I really believe it is on the basis that no one can check them. I like something which I can go on and say yes or no. Take cylinder bores, supposing in the cold state they are stated to be such a figure ; what are they in the extreme conditions of service ?

I am in the position of an interested listener and without trying to be critical I feel the subject is one we have got to go very cautiously about. The suggestions are such as give us confidence to go ahead. I would not say we can attain these extremely fine accuracies commercially. There is a very real item of cost which is easily forgotten. I do like the circular machine. I have made circular machines for certain accurate work which did the work. The circular machine is much more easily produced and in practice it affords no real difficulty in upkeep.

Mr. Platt : I was very interested in the cost of this fine accuracy. Regarding Mr. MacFarlane's standpoint of direct assembling we have found in recent years these limits have been closed down from three-quarters to half of a thousandth in the hope that more direct assembling would result. In many cases that has been so but in other cases selective assembling has been more in evidence. I would like his view about producing half inch diameter parts—the difference between half a thousandth. Regarding the machine tool people, personally, I think 95 per cent. of all accuracy is what is put into the machine tool or small tool. Another little point is the actual cost of fine accuracy as exemplified by catalogues of gauge block makers. Taking two where the accuracies run to fine accuracies the costs are entirely different. In one taking the coarsest shop finish to be datum line, for base accuracy of eight millionths to get six millionths they only require an increase in price of 22 per cent., and to get the reference set of 3.2 millionths they require 58 per cent. increase over the datum. This is not great compared with another where the base accuracy of shop finish is 10 millionths. For five millionths the increase is 33 per cent. and for 2½ millionths it is 107 per cent.

Mr. MacFarlane : Gauges. I think it is not a question of method there but a question of policy of the two different firms

concerned. I think it will be realised where one firm is producing precision gauges of three different types they arrive at these grades by a process of selection at the final stages. If you can measure them it is a question of policy what percentage of the blocks which would pass as reference Grade " A " find their way into grades " B " and " C." I think that is where the difference will chiefly lie.

MR. WRIGHT (Section President): I think, in connection with the paper, I must agree with most of the speakers in regard to the figures mentioned—they certainly are far removed from anything I have to deal with or anything I want to deal with. He mentioned we are only controlled in our accuracy by our available means for gauging. I do not think we have even reached that stage. I have seen what appears to be a very fine lapped job or a very fine ground thread which, when projected on the screen, looked like a mountain contour.

He has made it sound very simple and there is no doubt about the tendency to produce parts to finer accuracy. His remarks are well worth considering, but as regards costs it certainly looks as if it is going to cost us an effort, if nothing else, to attain the limits mentioned to-night.

MR. CLAYTON: In reply to Mr. MacFarlane, who asks how firms working to a degree of accuracy of .00001 are able to measure so accurately under commercial conditions. The measuring machine is used. This machine, far from being delicate, is most robust and can be erected in the average workshop and in upper stories. No special building is required and ordinary vibration can be disregarded. Indeed, this is the chief advantage which the measuring machine has over all other forms of extremely accurate gauging or measuring devices. There are scores of these machines in use throughout the country. When I was chief inspector with Chelsea Precision Tools, Ltd., London, I used a Newall measuring machine. It stood on a truncated pyramid made of concrete; the temperature of the shop was kept as equable as could be; the machine could always be relied upon to measure accurately to .00001 inch. I carried out a series of tests of the machines' reliability; a test-piece was measured by a number of tradesmen after brief instruction in the use of the machine, as none of them had ever used it before. Each man wrote his size upon a piece of paper, and all the figures agreed to .00001 inch. I mention this to show how simple it is to measure to the fifth decimal place. In connection with the cost of measuring mentioned by Mr. MacFarlane. It may interest you to know that a piece, a fraction of an inch in diameter, can be measured to .00001 inch, the machine broken down, calibrated by means of a one-inch test piece and a second part or gauge between one and two inches in diameter can be measured to .00001 inch in less than two minutes. The time required to measure 50 pieces of about the

same nominal size to .00001 is four minutes. In a forty-seven hour week 20,000 measurements can be made to .00001 inch. This leaves twenty-four hours for re-setting the machine, sufficient time, that is to re-set it about 400 times. The machine only needs re-setting when the piece differs in size by more than one inch from that previously measured and the cost per measurement is .048 pence, paying the operator of the machine £4 per week. I have no interest in the sale of these machines. Dealing with the cost of gauges in general, my point of view is that, high purchase price does not of necessity indicate high cost of manufacture. I believe the time is coming when gauge manufacture and design will be subjected to a thorough investigation and be placed upon a proper production basis with time allowances for all processes. This will speedily bring the accurate gauge within the reach of a vastly wider circle of potential purchasers and so in the end be good for the gauge industry. The wear of the gauge will become a matter of less and less importance in the near future both from the cost and the mechanical standpoint. Developments are taking place in this field tending to remove the necessity for physical contact between the gauge and the part. I used to believe that interferometry might have a popular future in the gauging field but it is useless save under the most rigid laboratory conditions or where cost of measuring is of no moment. I should like to mention that all the limits mentioned in the paper are actually being worked to in this country to-day.

Replying to Mr. Kirkwood. The need for better machine tools referred to by Mr. Kirkwood is very real and as I have tried to show in the paper, something is being done. We must remember that twenty years ago you could not buy any kind of machine capable of working to .0005 inch by means of a cutting edge. Again with reference to screw threads, you will recall that my view as expressed in the paper is at one with that of Mr. Kirkwood. You cannot procure screw threads to anything like fine limits commercially although, as stated by Mr. Kirkwood the case is even worse than I suspected. It would seem that little or nothing has been done in that field. Personally, I do not regard it as difficult to produce screw threads to a tolerance of .0015 inch on effective diameter. There is one point here that must not be overlooked. A pitch error can be compensated for at the cost of reducing the effective diameter of the thread by an amount equal to twice the pitch error. It is thus possible for the maker to reduce the effective diameter mentioned by Mr. Kirkwood by, say, .004 inch to compensate for a pitch error of .002 inch. The N.P.L. will pass a screw gauge with a pitch error of .0003 if the effective diameter is reduced by .0006 inch. Mr. Kirkwood is correct in supposing that rifle barrels are bored by means of a " U " section drill. The legs of

the "U" are drilled to take lubricant and the cuttings return between the legs of the "U." With reference to the question of workshop temperature ; this, as a tool in engineering, has never received the attention it deserves from management. I think that if the workmen are not allowed to interfere with the temperature of the workshops or deliberately to raise or lower the temperature of a piece of work for purposes of their own a step in the right direction would be taken. In my opinion rapid acting thermometers should be suspended in different parts of a room and not nearer to a wall than six feet. A rapid acting thermometer will rise or fall at the rate of 30 degrees F. in six seconds, and can be laid in a non-ferrous part suspected of a high temperature due to work done, etc. I am surprised that special forms of these same thermometers capable of making contact with a large area of surface have not made their appearance before this but doubtless they will.

With reference to Mr. Buchanan's query about holding work whilst machining to fine limits with special reference to centre work. There is at present no engine lathe capable of cutting metal with an edge tool to a limit of .0001 inch consistently over a period. As I see it the first requirement lies in the work itself which should reach the finishing operation sized to a limit of plus or minus .0006 inch. This ensures the finishing tool always having about the same amount of material to remove ; a most important point. Personally, I do not think it will be impossible to build a lathe to cut to a limit of plus or minus .0001 inch consistently over a long period, provided it has a cutting edge of diamond or cemented carbide. The demand will create the supply. Such a machine will have much in common with those mentioned in the paper which already exist and perform fine boring operations to a tolerance of .0003 inch. Unfortunately, such a machine would not be able to make use of dead centres, even of cemented carbide owing to the heat generated by the friction of the rotating work in contact with the stationary centres. With such parts as can be mechanically lapped the deformation due to holding of the work does not exist because, to all intents and purposes the work is not held.

With reference to Mr. Woof's query about the reconditioning of machine tools equipped with sliding parts of cylindrical form. The first point to consider is how often does a machine require to be overhauled ? Another point is that what I have in mind are cylinders made of steel, hardened, ground, and lapped. These would possibly not require to be reconditioned as frequently as the scraped beds of to-day. Further, owing to the manner in which forms such as those I have suggested lend themselves to cheap production as well as the most exquisite accuracy, reconditioning might become a factor of no consequence from the cost standpoint.

In reply to Mr. Mallet's inquiry about the station type machine mentioned in the paper. The tolerance is .0005 inch. The machine is used also for thread milling, and like the broach, has the advantage that the finishing cutter has very little work to do. It can naturally produce more accurate threads than any process save milling. I agree with Mr. Mallet that diamond dust is the most efficient medium abrasive for use in lapping.

To Mr. Pate. I should like to say that the title of the paper was chosen for me. Perhaps "The Quest of Fine Accuracy" would have been a more accurate one. At the same time, as I prepared the paper, it seemed to me that it was of greater importance to briefly sketch the present position with regard to the movement or tendency, undoubtedly in being, to reduce working tolerances, than to labour the paper with pages of tabulated figures which might easily prove of no value to us in discussion. As I said in the paper the change is being forced upon us by public opinion and above all by competition for business. Only a few weeks ago a famous maker of automobiles said: "A few years ago we wanted a thousandth of an inch; now we want a tenth of a thousandth of an inch." From the point of view of the manufacturer I would say that fine accuracy will not reduce profits any more than the car of to-day has done so in comparison with its pre-war predecessor. Regarding the use of the words tolerance and limit. I agree it would be better to drop one of them if that were possible. Unfortunately it is a little difficult to do so because most designers use the word "tolerance" to indicate the permissible deviation and "limit" to locate that deviation as for instance, plus .001 minus .0005 inch.

I think the costs Mr. Platt has given are very interesting. The point can be advanced that accuracy, where it has been achieved in the manner mentioned in the paper, has cost nothing. That is to say, no one is a penny the poorer for its introduction. On the contrary. I cannot conceive any manufacturer in the world embarking on a policy of reducing his working tolerances without maintaining or increasing his profit percentage in the result.

MACHINING OF HEAVY ENGINE PARTS.

Paper presented to the Institution, Coventry Section, by G. Hey, M.I.P.E., Section President.

IN deciding upon a subject for a paper to be given before the Institution, the author had in mind the fact that few production engineers to-day have experience on producing heavy engine parts, as many of the firms engaged on heavy engineering work have been very badly hit since the War. The dearth of shipbuilding, steel production, etc., has resulted in many of these firms being either closed or having to launch out in other directions. The author, therefore, considered that a paper of a practical nature, giving the machining operations on heavy engine work, would be of educational value to many, and chose as an example a 2,000 h.p. gas engine (many of which were built before the War in this country) as an example of machining processes.

The particular gas engine taken is one of 2,000 h.p. with four cylinders, approximately 48 inches diameter. The *crankshaft* is 24 inches diameter, weighing 24 tons. *Flywheel* 20 feet diameter, 26 inches face, weighing 40 tons. The *connecting rods* nine inches diameter, approximately eight feet long. The *piston pin* $5\frac{1}{2}$ inches diameter. These few dimensions will give an idea of the size of the engine. The total length of the *bedplate* was 65 feet and this was built in three sections, or girders known as, left, centre, and right hand girders.

The designer of the engine had a first class knowledge of machining processes, and throughout the design, had always considered the producing of the parts, so that the machining operations were easily carried out, and alignments were easily obtained. Although this engine has been taken as an example, machining methods of other engines will be discussed. We will commence first with the bedplates. The machining of the sections on the engine was carried out as follows :

1st Operation. The girders are machined on a horizontal spindle machine which was termed a " rotary planer," the operation being to machine the base. This was carried out with a 36-inch diameter inserted tooth facing head, the cutters being of one inch square section and shaped similar to an ordinary lathe roughing tool. The feed was approximately L-inch per revolution of cutter, and the depth of cut varied from $\frac{3}{8}$-inch to $\frac{3}{4}$-inch. Revolution of cutter, six per minute = 11 feet per hour approximately. It should be pointed out that in castings of this size, there is always the question of

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distortion and thereby the faces to be machined may be either hollow or round, according to the nature of the casting. In these particular castings there was a slight roundness, that is, heavier depth of cut in the centre, although the patterns to produce the castings had a camber of approximately 2½ inches in the length of the casting, and eight inches in the length the narrow way.

After the roughing cut, a 36-inch finishing head was fitted to the spindle with cutters one-inch face width. The feed was approximately two inches per revolution of the cutter. These beds were then placed on their sides and the faces for attaching the distance pieces, trays, and cylinders, were machined. Before commencing to machine, however, a centre line was marked on the casting. This was done by stretching a piano wire across the top the whole length, and the line marked from this. It was not satisfactory to mark this line while the girders were on their side owing to the sag of a casting of this length. These faces were machined with the same heads and on the same machine. For boring the crankshaft bores an outboard support is used, and a boring bar with boring head used, so that the faces and bores are square and true.

With regard to this machine, it should be pointed out that the floor plates extend the whole length of the machine which is approximately 80 feet, so that while machining is taking place on one piece of work, a second piece can be set up ready for machining, and while the first piece is being either changed or set up for another operation. By this means the machine is kept continuously cutting.

With regard to machining of bedplates for other engines, some of which were vertical, these were machined in addition to the above mentioned method, by planing, and also by milling. The decision as to which is the best method has to be governed by conditions. For constantly changing design, no doubt the rotary planer or the planer of the Stirk type, are most suitable, but where a repetition of one particular design can be relied upon, the Plano milling machine has its advantages.

We take next the machining of Diesel engine columns on a Stirk planer. These also have been machined successfully on a double headed Kearns machine, which is the method adopted by some of the firms on the North East coast. To decide which is the best method is controlled by quantities. One method is to rough the columns out on the planing machine, and then to transfer to a Kearns machine, bore the registers and cylinders (where the latter are cast integral with the column), finish face the feet so that same are square with bore, and mill in the register for setting on the bedplate. The latter method is recommended owing to the fact that when the boring and other operations are performed, a certain amount of distortion takes place, as the strains in the casting are released, thereby

necessitating that the face of the feet should be the last operation to ensure these being square with the bores and registers.

An open side planer is necessary for wide bedplates which are too wide to pass between the housing, or have some obstruction which make it advisable to use this type of machine. On certain marine engines, this was the only type of machine suitable for some of the planing operations. The Harvey vertical column horizontal machine for drilling bedplates is more or less standard practice for the drilling of these parts. This type combined with heavy or portable radials, make the most suitable combination for the drilling of the various holes on the heavier pieces. A large Kendall & Gent Plano milling machine, specially built for the machining of marine engine base plates for the Japanese Navy, has recently been supplied and is capable of dealing with all forms of machining which this particular type of bed or base plate calls for. As stated, the machine was supplied to the Japanese Government Dockyards and is the ideal machine where production on a large scale has to be considered.

Cylinders.

For the machining of large cylinders, the usual practice is to bore these horizontally using large boring bars, carrying boring heads and facing heads on the bars. The difficulty with these bars is to keep them true and concentric, as some of these are 36 inches diameter × 60 feet long. It is the practice in some cases to make them of cast iron with a cored hole through the centre. The difficulty is, that should the core sag so as to cause the middle of the boring bar to be thin on one side and thick on the other, the bar will sooner or later distort, and be out of truth. A further danger is that where the feed screw is let into the bar for the boring heads, this also has a decided tendency to cause the bar to run out of truth. It is the practice with these large bars to cut two or three grooves in the bar, so as to balance the strains towards this distortion. A much better method, however, is to use a bar running in fixed bearings with a fixed work head and travel the bar with these fixed bearings, or alternatively, to travel the work on the machine. This method ensures a parallel bore, whereas with the first method, should the bars have distorted and be running out of truth, the bore varies in diameter according to the amount of distortion in the bar. It is surprising what amount of errors can be created by this one fault.

It is the usual practice in some of the large shops to rough bore the cylinders. Boring the heads travelling by screws, that is one screw to each work head, so that two or three roughing cuts can be taken through the cylinder at the same time. After the rough boring, the cylinder is transferred to other machining operations such as facing the water flanges, milling the sides and registers for

fixing to the girder bedplates, etc., and the various drilling operations carried out. They are then set up on a boring machine with fixed work heads, and the final boring taking place by travelling the cylinder on the bed. These remarks apply also to cylinder liners on the larger sizes.

On the vertical type of engines where the bedplates are of the flat type and crankcases are bolted on to same, the boring bars, as mentioned above, are carried in bearings, which are in the form of brackets and rest on the top of the bed itself. These brackets are machined so as to give the boring bar the correct height for the centre of the main bearing bores. It is the usual practice to true up the boring bars periodically by grinding, in some cases once a month, and to fit bushes in the boring heads and brackets to suit the diameter of bar ; new bushes are fitted after each truing operation. This was the practice in several of the large engine shops. It is usual to carry as many boring heads as there are bearings to bore, so that all the bearings are roughed out at the same time. The boring bars carry two or three screws equally spaced for feeding the heads forward, thereby distributing the thrust and load more evenly. The feed is by epicyclic gears at the end of the bars attached to the outside support bracket with idler gears meshing to the gear on the end of each screw.

Another method is to use a star wheel on the end of each screw, which is tripped each revolution of the bar to give the screw a slight turn. The boring heads in some cases are in halves and are removed and finishing heads with cutters accurately set to size fitted in their place. In other cases where the roughing heads are solid the finishing heads consist of a section of rings which are slipped over the boring bar and are a sliding fit on a portion of the roughing head. The finishing cutters in these cases are accurately set for size, etc., before fitting to the roughing head. The brackets carrying the boring bar are spaced between the bearings to be bored, but must be of such a width as to allow sufficient room for the boring heads also. These brackets have caps on the bearings, so that the bar can be lifted clear. The bearings for the feed screws are also removable so that the bar can be quickly dismantled.

After the operations of boring and facing, the method of drilling the various faces is catered for by jigs of the plate type, but designed so that they can be attached to the various faces, registering in the bores, and interlocked with each other so that when assembled round the cylinder, they form an integral part, and each one is correctly registered relative to the others. This method has been adopted by most of the large engine builders and is comparatively cheap and efficient.

Dealing with cylinder liners, these are machined as mentioned above on the larger engines, but on the smaller type the same

principles apply but in a different manner. In the Craven cylinder liner boring machine, the bed is arranged so that the two non-rotating concentric chucks are adjustable for varying lengths of liners, and grip the liners in a central position relative to the boring bar. As stated, the liner does not rotate. The boring bar is driven from a variable speed motor, provided with traversing type of multiple cutter head, this having screw traverse, arranged to take the roughing cut in one direction through the liner, and to cut in the opposite direction for finishing, thus no hand winding or hand movement to the tool head is required. The boring bar is supported in an outer pedestal, which can be adjusted from the bar and lowered to enable the liners to be placed on the bar and through the chuck. The machine is intended to deal with both steel and cast iron liners. mainly for steel, however, for large Diesel engines.

After boring the liners are turned and a final boring cut has to be taken through the liner which distorts during the turning operation. Drive is by spur reduction gear from a variable speed motor through a worm gear on to the driving sleeves to ensure smooth running. The headstocks may be driven together or independently. All gearing is totally enclosed and running in oil, ball or roller bearing being used wherever necessary, and all bearings are lubricated by the " one shot " system. Spindle speeds are six to 18 r.p.m., feed is 16 to 48 cuts per inch, horsepower 20.

The liner, 14-ins. bore × 3-ft. 8-ins. long, is held in a 25-inch Coventry chuck fitted with special jaws for gripping. One end is turned for about six inches and faced. The liner is then turned round, and held on the turned portion, and chamfered in the bore to suit a conical steady held in the hexagon turret. The outside is then turned and finished to dimensions with tools held in the square turret. A three point steady is fixed to the lathe bed and adjusted to the liner.

The conical steady is now removed and the boring commenced. The bore is machined for a short distance with a boring head held on a short stub bar. The roughing head on the long bar is now inserted and the roughing cut taken. A revolving support is carried on the bar immediately behind the boring head to prevent chatter. To start the bore for the finishing head, a single point tool is used to ensure the bore being concentric with the outside, and the bore sized for a short distance. The finishing head, complete with supporting bush is then interchanged with the roughing head and the liner finished bored. After this a sizing head is interchanged with the finishing head that has floating cutters and sizes the liner to an accuracy of plus or minus .0005.

The particular type of snout boring machine I refer to next was developed on the Continent, and many such machines are in use in this country. The Craven and the Herbert machines revolve

the work while the tools are stationary, and in the other the tools revolve while the work is stationary. The large snout which runs out from the headstock supports the boring bar to the end that carries the boring head. This snout can be of large size, only allowing for clearance in the cylinder, after the boring head has passed through. The boring head carries several cutters, which can be easily ground and adjusted, being made of square section high speed steel. A larger size of borer in these works has a 24-inch bar carrying a four feet diameter boring head. The snout has seven feet overhang allowing with the boring head a cylinder or liner eight feet long to be bored.

The drive to the boring head is through worm and wormwheel. The wormwheel being of large diameter a steady cut without chatter is obtained. The roughing head has two rows of cutters, the cutters being staggered, the second row taking a second roughing cut to bring the bore within .030 of size. The roughing head is now removed and the finishing head fitted. The finishing head carries only one cutter and the head is supported behind the cutter by six hard wood blocks, adjusted to fit the finished size. Slots for holding the blocks are cast in the head, the blocks are made a tight fit in same and are adjusted by wedges underneath the blocks. After this finishing cut, honing stones are inserted in the head and the liner honed parallel to within .004 in the length and .002 in diameter and roundness.

I now come to a vertical machine for boring cylinder liners. This method of boring, that is with the liners in a vertical position, has the advantage that the swarf and cuttings drop clean away as the boring takes place. The total height of the machine is over 30 feet and weighs 60 tons. The boring bar is 14 inches diameter. The feeds range from two to 20 cuts per inch. The machine, however, is not ideal, due to the fact that the liner has to be dropped over the boring bar, the head carrying the bar swivelling clear to allow the liner to be dropped into position. The boring head in this case travels up and down the bar with screw feed. A better design is where the boring bar is carried on a vertical slide similar to those shown in the horizontal machines, the bar travelling upwards sufficiently to enable the liner to be inserted at floor level. The whole of the bar then travels with the boring head fixed on the end, the slide being of sufficient length to ensure rigidity and true guidance. In fact, the machine is a vertical snout borer. By the vertical method the base of the fixture for the liner can be open, so that the swarf immediately drops into a pit below the machine.

Crankshaft.

We now pass to the machining of crankshafts. As this is one of the most important parts of the engine, it is essential that same

should be a first class job. I, therefore, propose to deal with the method in detail of machining large crankshafts from the forging state to the finished shaft as quickly as possible, explaining the various points to be guarded against, and how to obtain the best results from the machines.

Let us take a three-throw crankshaft, 18 inches diameter. The forging should first be measured both for length and diameter to make certain that it will clean up to drawing dimensions. Next mark out the widths of the webs, and the centres of the pins, and centre the shaft true to the portion having the least metal to be removed.

For a shaft of this size, the centres require to be approximately two inches diameter and clearance holes drilled up, which are usually filled with Russian tallow or white lead. The shaft is then put in the lathe. Commence to rough down the sides of the middle throw to $\frac{1}{8}$-inch of size and then follow with the others. At the same time one corner should be roughed out to within $\frac{1}{4}$-inch of the drawing figures for about two inches along the shaft ; the other corner should be left the finished width of the web for about $\frac{3}{4}$-inch along the shaft. This latter is a guide for machining the webs to correct width and concentric with the shaft. If the tops of the webs are to be turned, these should be done to within $\frac{1}{16}$-inch of size. The body is also roughed to within $\frac{1}{4}$-inch of drawing size and the shaft faced or parted down to length, allowing $\frac{1}{4}$-inch for final ending off.

The next operation is to shape or slot the webs to the required width, after which they can be drilled and sawn out, or can be gashed out on a machine designed for removing this surplus metal. It might be added also that the Puncher slotter takes the place of the band saw in many works for removing this piece of metal. The crank is now returned to the lathe, the ends faced to length and permanent centres put in. One practice is to bore the ends of these shafts a standard taper, so that hardened steel centres can be fitted which are removed after the shaft is completed, and should the shaft be returned at any time for repairs or any alterations, the centres can be refitted, ensuring a true running shaft.

After the hardened centres have been fitted, the shaft is turned down to receive the throw blocks, which are usally bored $\frac{1}{8}$-inch larger than the finished diameter of the shaft. A common type of block, used for two and three throw cranks, has the steel centres projecting outside the block, being all one diameter, which are the same as the hardened centres fitted in the end of the shaft. These facilitate setting the blocks in relation to the throws.

After turning the end for these blocks a strip about $1\frac{1}{4}$ inches wide should be finished some definite size near each end of the shaft, which is afterwards used for checking up the setting of the blocks when the pins are being turned. The crank is now taken from the

lathe, placed on a surface plate, or some other flat surface, and the throw blocks fitted on, the centres in the blocks being brought to the same height as the centre in the shaft at each end by using a surface gauge or indicator, making sure that the blocks do not move when tightened. The crank is again put in the lathe on the centres for turning the middle pin and this is roughed down to within $\frac{1}{4}$-inch of the finished diameter, then the insides of the web are roughed to within $\frac{1}{16}$-inch of width. Now take out the crank and put it on the centre for one of the other throws and proceed in a like manner until all the pins are roughed out ; now put the shaft back in the lathe for finishing the middle pin and at this stage, test the machined strips at each end of the shaft with a scribing block or indicator placed on the lathe bed.

This will show if the blocks have moved in the roughing out process, as these turned portions should show level when the shaft is in any position, but if there is a discrepancy, one of the blocks should be slackened and the shaft set until these strips both show the same height from the lathe bed.

Assured that the blocks are correct, proceed to rough the pins within $\frac{1}{16}$-inch of size, finish sides of the web to drawing width, and finish radii in corners of pins.

These radii should be 0.010-inch smaller than the diameter of the pin. Next water cut the pin to within 0.004-inch of the drawing size, proceeding with the others in a similar manner. When all are finished, the shaft is placed on its own centres and the pins tested for alignment. To use the tester referred to, a straight edge is clamped in the tool post and set with a square from the crank. The tester is then put on the pin, being a snug fit endwise between the webs and the pointer is adjusted to touch the straightedge when the crank is right in. The crank is now revolved and readings taken at the bottom at the right out position, and at the top. If the pointer touches the straightedge at the four points, the pin is true and parallel to the shaft, but if not, the indicator will show the exact point and direction the pin is out of parallel, and it must be filed and trued in some way to bring it in line when the pin can be lapped true with a lap.

The lap has four adjusting screws in the top half which enables the lap to be adjusted for diameter and prevents the lap hunting the shaft. A pin out of round can be lapped round in half the time that would be needed if these screws were not used. The throw blocks should next be removed and while the shaft is at rest out of the lathe, the steady pieces should be fitted. The shaft is now put back in the lathe, and the outside checks of the webs finished and the radii in corners finished to 0.010-inch less than drawing size, similar to the pins. Also finish the top of the webs and rough over the shaft body to within 0.015-inch, and then water cut to within 0.002-inch, afterwards lapping to size and the shaft is completed.

When turning long shafts and shafts with long throws, an eccentric and steady are recommended. The steady is bored to suit the diameter of the shaft and the centres of the bores are the same as the throw of the crank. It is bolted to the shaft and the eccentric fitted on to the tongue and bolted through the bolt holes. For setting sideways, the set screws are tightened against the webs of the crank, and when adjusted the bolts are tightened up solid and the eccentric is run in the ordinary lathe steady rest.

Connecting Rods.

The particular rod taken is for a small engine 500 h.p. The rod is nine inches diameter $\times$ nine feet long. The first operation is to centre the rod at each end, the turning being carried out on a centre lathe provided with two saddles, the one having a top slide with a circular feed for machining the large radii, and a former plate attached to the tailstock for forming the shaped end. The faces are machined on a double headed shaper for machining cranks.

The small end is roughed out on a heavy duty drilling machine and opened out with piloted single point boring tools. This operation can also be performed on a Kearns or Richards horizontal machine. The forging at the large end has a hole punched through, so that a bar can be inserted through this for opening out. The method adopted is to trepan this piece out. This method has proved the most rapid way of removing the surplus metal and can be trepanned to within $\frac{1}{8}$-inch of finished size. The interesting point about the trepanning, too, is that the two cutters in each head are set at a slightly different radius to each other, therefore cutting a wider groove than the width of the tools. Instead of clearance being put on the blades, they are seated at an angle to give their own clearance so that the cutter cutting on the outside diameter clears inwards, and the cutter on the inner side, has clearance outwards. This simplifies the method of the cutting tools and owing to the fact that the groove is much wider than the tools, the chips are able to fall away easily. A further point is, that the tools can be set with very little overhang for the commencement of the cut, and as the cutters penetrate deeper, they are extended until the required depth is obtained. There is no other point of interest on the rods.

The piston rods have a large flange at one end turned to fit a register in the piston and held by bolts. The turning, drilling, and grinding are done on standard machines.

We now come to machining of flywheels. The lathe used was a home made product, as the quantities produced did not justify the expenditure of several thousands of pounds, required for a machine made by a machine tool builder. A pit was made in the form of a half circle 36-inches wide, and was concreted up to the

ground level and three hydraulic jacks were let in each side for setting and holding the wheel in the pit. Two sliding blocks across the pit at 70 degrees angle were also fitted and moved by similar jacks for raising and lowering the wheel.

Two cast iron girders were made 18 inches deep × 10 inches wide, and bedded along each side of the pit. Two shorter girders were fitted to act as distance pieces at each end, and also to carry the slide for turning the rim. Two short slides were fixed one each side of the turning slide for facing the rim. Bearing castings were made for carrying the boring bars and the mandrils for turning. An extension on each of these brackets carries slides for turning and facing the bosses, and also to carry the gear for driving the boring bar. The back distance piece carries gearing for use in driving the wheel, for turning. This gearing is driven from a countershaft. A steel pinion on this gearing meshes with the teeth cast in the flywheel and gives a powerful drive. The cost of this machine complete, including excavating, concreting, and jacks, etc., was £1,150.

In operation, a flywheel is dropped into the pit. A boring bar is passed through the bore and a trammel rod fitted to reach the face of the rim. The wheel is then adjusted by the side jacks until true on the face to the trammel rod. Next the trammel rod is set to the outside diameter of the wheel, and the two jacks are operated for raising or lowering, until the wheel is shown to be true with the boring bar.

The first operation is boring—and roughing and finishing heads are used. The usual screw feed is used, the screws being operated by an epicylic train of gears. After boring, the bar is removed, and the next operation is to fit a mandrel on which are conical bushes and these are pulled into the bore., with bolts through the two conical bushes, and the mandrel is then dropped in the bearings. The jacks are now released. To revolve the wheel the pinion is meshed into the cast teeth on the wheel, and this revolves the wheel for turning. For the turning operation five tools are at work at the same time, two tool boxes facing the outside rim, one turning the outside of the wheel and one each side turning and facing the bosses.

A crowning arrangement is fitted so that the flywheel can be crowned for a belt or similar drive if required. After the completion of the turning, the jacks are again brought into use to hold the wheel, and the mandrel is removed from the bore. A portable slotting bar is then fitted and two keyways 4½ inches wide × two inches deep are cut through the flywheel. The total machining time for this wheel is 450 hours.

In the case of a boring mill engaged on a plate flywheel, it is customary for boring mills of this type to have a revolving tool arrangement in the centre ram, so as to obtain a higher cutting speed for

the boring of the wheel, while the other parts are being turned. If this is not available, then the correct method to adopt is, while the boring is taking place, the turning, and facing of the boss should be carried out with the second ram. These should be roughed out and the next operation is for one of the rams to face the two opposite rims while the second rim is turning the outside diameter. These can then be finished and polished if necessary, the final operation being to size the bore.

With regard to the main bearings and the connecting rod big end bearings, these are made with either cast iron or cast steel shells. The usual practice is to plane or mill the joint faces and then to rough bore and cut dovetail grooves round same, with similar grooves at right angles for holding the white metal.

The boring being done on a boring mill, the cross dovetail grooving is then carried out on a small planing machine doing several bearings at one setting. For engines that have to run long periods without stopping and where breakdowns are of a very serious nature, another method is adopted for holding the white metal. In place of the dovetail grooving, the bearings are made larger and are studded with phosphor bronze plugs. That is to say, the shells are drilled with a large number of holes and tapped a fine thread and short phosphor bronze plugs are screwed tightly into these. These plugs are then bored approximately $\frac{1}{4}$-inch larger than the finished size of the shaft. The bearings are then white metalled and the white metal bored to size. The object of this method of holding is, that should the white metal be melted and run out due to heated bearings, the engine can still run on the phosphor bronze plugs until such time as it is possible to shut down. This, in large steel works, paper mills, and pumping stations, is a very important point. The other operations on these parts are carried out on standard machines.

On the engine first dealt with, the cams for operating the valves present interesting methods for cutting the cam tracks. As these cams are of comparatively large diameter, being 24 inches diameter, the cam tracks $4\frac{3}{4}$ inches wide being taper and the tracks cut from the solid, a heavy Kendall & Gent vertical milling machine was used for the job. The cross traverse screw was removed and air cylinders were inserted in its place.

The fixture for holding and revolving the cams had a self contained motor drive with double worm and worm wheel reduction. A bracket from the column of the machine carried a roller fitting a cam of duplicate shape in the track to the one to be cut which was also carried on the fixture. This gave the correct motion so that the conical cutter in the machine could cut the track to the required shape and size. Springs and weights were not satisfactory. A by-pass in the air cylinder was automatically controlled by the cam former, so that the pressure was regulated to suit the cutting.

Owing to the tremendous load on the exhaust valves, hardened steel insert were afterwards fitted on the rising side of the exhaust cams.

The turning and boring operations on these cams were carried out on large Lang lathes, and the keyways cut on standard keyseating machine. The cam shafts, owing to their great length, presented an interesting problem for cutting the keyways at the correct angles for positioning the cams. This was overcome by making an attachment to fit on one end of the cam shaft in the form of a disc with holes spaced near its outside diameter corresponding to the angles of the various keyways, and stamped opposite each hole the keyway to be cut as No. 1, 2, 3, etc. A boss on the disc carried an arm which had a spring plunger to fit the holes in the disc. A very highly sensitive spirit level was fitted into the arm and as the cam shaft was moved for cutting each keyway, the arm was located in the hole on the disc corresponding to same, and the level enabled the various angles to be obtained accurately and at very little trouble.

(*The Paper was illustrated throughout by lantern slides.*)

Discussion.

Mr. J. A. Boyes (Section Vice-President) who presided: Mr. Hey has taken some of us back home to-night—to Manchester, Glasgow, and the North-East coast, and they say that a change of occupation is as good as recreation. Well, to-night we have had a change. I have almost thought that Mr. Hey was telling us that Coventry is a Meccano centre and that real engineering is done at other places. He has not dealt with split seconds but with hours and weeks.

Mr. Drane: We must agree with our Chairman that we have listened to something beyond the majority of us this evening. It is very interesting to have something put before me that I, for one, do not know a great deal about. There are one or two elementary questions I would like to ask. For how long do you season the castings and how is the camber in the mould determined? The machining time of a flywheel was, I believe, 450 hours. I am just wondering how inspection is done during that time. I should think there would be a lot of stress released during machining and at the end of forty-eight hours the job would be very different to what it was earlier on. On crankshafts I take it that lapping is always the final operation, and could you tell us how long it takes to lap and how much is left on for lapping?

Mr. Hey: With regard to seasoning of castings. I might say that on very large castings the moulds are thoroughly dried before the metal is poured, and after the cast the mould is left intact in some cases for a week so that internal strains are reduced to a minimum. From the fettling to the machining stage an average time of two weeks would ensue in the case of the bedplates, but as only approximately 20 per cent. of the casting surface is machined no distortion takes place.

In the case of the flywheels; these are cast in four sections owing to the very heavy sections of metal in the rim and boss. If cast in one piece the arms would crack in cooling in the mould owing to the small section of metal in the arms compared with the rim and boss. In other words the metal in the arms would solidify long before the rim and as the rim commenced to solidify and therefore to contract, fracture would inevitably result. The seasoning period would probably be one month from fettling to the machining stage.

With regard to camber. The camber is put on the patterns and these are reinforced by angle-iron built in so that the ramming of the pattern will not distort same. The mould therefore gives the necessary camber from the pattern.

With regard to the machining time of the flywheel. The time stated was for the turning, boring, and keywaying operations and did not include maching the faces of the four sections nor the machining of the joggle slots. The first operation is to machine one face of each segment and then machine joggle slots at the same setting. These slots are slightly taper. Two quarter segments are then put together and the joggles fitted in the rim and tightened by bolts to pull the two quarters together. This now gives a half wheel and the joint of these are now machined in a similar manner and the two halves fitted together to form the complete wheel. The total machining time for these operations is 120 hours per wheel. With regard to inspection, this takes place on the completion of each operation, but before removal from the machine.

With regard to crankshafts. I mentioned two-thousandths for lapping, but on some pins eight to 10 thousandths is necessary. It depends a great deal on the turner. A good heavy crankshaft turner is " worth his weight in gold." With a good turner the pins will be found true and square in ninety-nine cases out of the hundred. The testing apparatus shows any error in alignment, also the amount, and the exact position or location. Years ago it was my duty to inspect large shafts for battleships and large engines in all parts of the country, and in many cases I had to teach the turner the importance of balancing the shafts to get roundness and alignment. The only remedy for correcting mis-alignment was to file the pins on the opposite side and then to lap round and parallel. The time taken to lap an 18-inch crankpin removing approximately 15 thousandths. is three hours, using carborundum and oil for roughing and finishing with fine dust, finally crocus powder or rouge powder. It is most important that all the journals are accurate to size and *all the same size*. It is not a case of should be—but they must be. If one journal is two thousandths smaller than the other—the others must be lapped down to the smallest. If this is not done, the fitting shop will have hours of scraping bearings to get the shaft bedded.

The total machining time for a crankshaft as shown is about 200 hours for the lathe, and about eighty hours for the slotting or shaping of webs and keyways. The time from commencing on the forging to finishing the shaft may be eight or ten weeks as periods elapse between the various operations to allow stresses to release themselves—particularly after the roughing operations.

Mr. Drane : With reference to machining of liners. On combination turret lathe multi-tools are used for rough boring and finishing and tools are carried in a square turret. How does the machining time of combination turret lathes compare with the other method described where on two Craven lathes the cylinder liner was held rigid whilst rough bored and then taken out and turned up and

finished ? Have you any idea of machining time by that method ?

MR. HEY : The maching time on the Craven lathe is $2\frac{1}{2}$ hours for roughing and one hour for finishing. With regard to which is the best method, this depends on conditions—finance and output being the most important. The Turret lathe is more expensive than the single purpose machine, but where there is not sufficient work to keep a machine continuously on the one job, then the turret lathe presents advantages as the same can be used on other work. On the other hand, if quantities are required then the single purpose machine has advantages as although the time may be longer one operator can look after two or three machines. On the large snout boring machine the time to bore and cut off the rise of a cylinder liner 4-ft. 6-in. diameter × 7-ft. 6-in. long is twenty-two hours for boring and four hours for cutting off the riser and facing end.

MR. DRANE : What about tipped tools ?

MR. HEY : With regard to tipped tools, since I commenced on this paper, I have made enquiries with regard to the affect tipped tools have on this work. As mentioned in the paper so many of the firms previously engaged on this work are now closed down or engaged on other work, and it is therefore not possible to give much information on this subject. The opinions expressed to me by two separate firms are that for roughing tipped tools are not used, but have proved very satisfactory for the lighter and finishing cuts as higher speeds can be used and that a parallel bore can be obtained as the tool keeps its edge.

MR. TRUBSHAW : The lecture has been of particular interest to me as I commenced my production training on a similar class of work, only not so large. With reference to using a puncher slotter to remove the surplus metal between webs and cranks. I would like to mention that our experience was that it was cheaper to drill a hole and saw the bulk out than to punch, for two reasons, first that the labour was cheaper on the saw than the punch and also that when the puncher had finished there was nothing left but scrap while with the sawn method quite useful billets were obtained. The punch was never a paying proposition on that class of work. For removing the metal from connecting rod big ends the flame cutter was used the hole being finished bored to size on a pillar drill using a boring head with micrometer adjustment.

I should like to substantiate Mr. Hey's remarks re the value of good crankshaft turners ; they are men of first-class ability and I never knew the men we had to use a lap.

MR. HEY : With regard to puncher slotter, I have no data other than what I have gathered for this paper. A machine similar to the Schiess DeFries and Craven Crank Pin Turning machine has been in use for many years for gashing out for the pins, the

same machine being used to machine the tops of the webs. The difference was that the internal ring was fitted with inserted blades. The internal ring was approximately 40 inches and 40 blades were fitted about 2½-in. to 3-in. wide—blades staggered and serrated for breaking the chips. The ring was driven by worm wheel and worm. The worm wheel was on the outside of the internal ring and gave a very steady cut. The feed was one inch per minute for gashing. For turning the tops of web the same feed was used with a cut 1¼ inches deep. Recently I have seen a German band saw cutting out a web 18 inches deep at one inch per minute feed—a very good performance. The earlier machine mentioned takes five hours to remove the gap which, of course, is all chips. By machining the tops of all crank webs with this machine standard radii of balance weights could be produced, otherwise turning in the lathe would give different radii for each crank. With regard to trepanning connecting rods. The time to trepann a rod as shown was three to four hours. The boring to finished size at the same setting is 1½ hours. With flame cutting there is the question of the metal being hard from the cutting, also its affect on the structure of the metal and lastly the extra boring necessary compared with trepanning.

Mr. Trubshaw : My point was that we found it cheaper to cut out the big end with a flame cutter and bore than to use trepanning tools, the same are an expensive item and the rod would then have to be finished bored or ground. With reference to crankshaft turning, we installed a large rotary crankpin lathe and our experience was unfortunate and the machine never came up to expectations. During the time I was with the firm the machine was never used for finishing. In answer to Mr. Drane. On heavy casting like a flywheel we seasoned them for as long as possible—some for three months if the contract allowed it. They were allowed to " grow " in the yard as long a time as the contract would allow.

Mr. Parker : I do not think you have mentioned a method of operation for machining connecting rod facings. At Marshalls of Gainsborough we planed one side and then planed the other. Have you ever come across any method of facing connecting rods on a vertical milling machine ? With reference to seasoning of castings. Some of the castings were out in the yard getting on for three years !

Mr. Hey : With reference to machining bosses on connecting rods. These were done on double-headed shapers, and then turned over. Similar rods were put through on Muir double-headed milling machines, but as a similar machine was not available for large ones these were shaped.

Mr. Potts : When do they find out the forging is twisted and when it is not ? I should like to mention a point with regard to the drives to cutter heads of large lathes although I know it is

really outside the paper. You have mentioned the fact that a worm drive would be an improvement of various spur gear drives. I have looked in vain amongst heavy machines continually appearing in the press for an instance of a complete gear drive and putting chain drive at one stage. People do not appreciate the virtue of a chain drive when positive by changing the ratio of having elasticity to overcome any shocks to tools meeting hard spots. There is a great deal to be said in favour of chain drive somewhere within the complete drive. I should like to ask Mr. Hey if he has come up against the awakening of machine tool builders on that point ?

MR. HEY : Where a drive is what one might term a " direct on " drive, I am certain a chain drive would not be satisfactory. I have pointed out that a pinion and spur drive is not satisfactory owing to back-lash in the gearing re-acting on the tools. I have known two-inch square steel tools with a very small amount of overhang break one after another when the roughing cut has varied in depth. With a chain drive this trouble of reaction will be far greater. The worm and worm wheel drive is the only satisfactory drive for these heavy machines. The only place to use a chain drive would be where rebound of tool and vibration of cut could not be affected by a chain which must have some backlash and float.

With regard to ensuring that crankshafts are not twisted in forging, but forged to the correct angles of each crank ; it is usual practice, particularly on Admiralty work, for an inspector to see the shafts forged. A test piece also is forged and the inspector stamps the forging and test piece so that it is not possible to twist a forging without the customer knowing. A certificate is sent with the shaft to its destination giving any information that may be of use or necessary, also where the inspector's stamp is placed.

MR. COLE : When Mr. Hey was questioned about a flywheel he told us it is set in four sections. It has intrigued me to know how one lined up the teeth and the method of finishing.

MR. HEY : The joints are always at the centre of tooth spaces.

MR. COLE : Can you tell us what was the selling value of the 2,000 H.P. gas engine ?

MR. HEY : That is the easiest question I have had to-night. £5 per H.P. and you have finished.

MR. COLE : If one or two crankshafts are scrapped there must be a good margin of safety for profit.

MR. HEY : Very few are actually scrapped. The crank turners were magicians and it is very unfortunate it is now almost a lost art. The heavy engineering trade has gone dead. The trade union returns show only about five per cent. of what there were before the war.

A vote of thanks to Mr. Hey concluded the proceedings.